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Proof of Concept Tests: Data Acquisition and Analysis for Close Range Hazard Detection

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17. Abstract

An evaluation of a commercial fish-finding sonar in an iceberg detecting role was undertaken during July and August, 1984, in the Davis Strait/Baffin Island region of the Canadian Arctic. A C-Tech CDS-40A sonar with an operating frequency of 36 kHz was mounted within the hull of the icebreaking freighter, the MV Arctic, and lowered as required. The sonar was used in a program of sea trials during a 72-hour period on a voyage of the MV Arctic between Antwerp, Belgium, and Nanisivik in Baffin Island.

The results suggest that a commercially available calibrated sonar system can be used to obtain quantitative and qualitative data which relate echo level (amplitude) to iceberg size. Measurements of echo level from ice pieces less than 100 tonnes and very large icebergs greater than 10 million tonnes indicate a range in values of target strength from -15 db to 35 db per square metre. Also, variations up to 40 db in target strength were obtained from multiple measurements on particular icebergs.

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17. Résumé

L'essai d'un sonar utilisé en pêcherie commerciale et transposé à la détection et à la reconnaissance des icebergs a été effectué de juillet à août 1984 dans le détroit de Davis et au large de l'île de Baffin. Un sonar C-Tech CDS-40A fonctionnant à la fréquence d'émission de 36 kHz a été monté à l'intérieur de la quille du cargo brise-glace Arctic et mis en oeuvre de la façon requise. Cet essai a eu lieu dans le cadre d'un programme d'essais en mer de 72 heures au cours de la liaison régulière de ce vraquier entre Anvers (Belgique) et Nanisivik (Ile de Baffin).

Les essais ont montré qu'un sonar de type commercial et convenablement étalonné fournit des données qui permettent de déterminer la taille des icebergs d'après l'intensité des échos reçus. Le mesurage des échos réfléchis par des icebergs d'une taille allant de 100 à 10 millions de tonnes a mis en évidence une gamme d'intensité d'échos variant entre -15 et 35 dB par mètre carré. De même, des variations d'un maximum de 40 dB dans l'intensité des échos ont été constatées dans le cas de certains icebergs à la suite de mesurages multiples.

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The services of the two ice observers from Norland Science and Engineering and those of the C-Tech engineer in maintaining the sonar system contributed much to the success of the trials.

The final version of this report was produced with the assistance of Dr. P.G. Simpkin who reviewed the material and incorporated Canarctic Shipping Company's suggestions.

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1.0 INTRODUCTION

1.1 GENERAL COMMENTS

Safe navigation in Arctic waters has always presented a major problem to mariners. The presence of ice and icebergs demand the utmost vigilance on the part of ship's personnel. The expected increase in shipping activity, particularly with the transportation of hydrocarbons, coupled with the realization by commercial and government bodies that the marine environment is an important natural resource means that any new technological advances that may reduce the risk of collision should be evaluated. From a commercial viewpoint, the overall desire to find the quickest and safest route through Arctic waters results from economic considerations. Thus, any additions to present iceberg detecting systems should be of advantage. Radar has been the traditional method of detecting obstacles at sea. Radar systems have reached a relatively sophisticated stage but have certain limitations with respect to small targets, weather and sea conditions. As regards icebergs, approximately 9/10's of their mass is below the water line and thus, invisible to radar. In addition, icebergs may exhibit a low profile or have an illuminated face gently sloping with a very shallow grazing angle. Such conditions seriously affect the detectability of icebergs by radar even at close ranges. Sonar, therefore, should be considered as an alternative methodology for remote iceberg detection for the following reasons:

1. Sonar operates within a communication channel which is totally separate from marine radar. It can be considered as an adjunct to radar thereby reducing the probability of missed targets.

2. The major portion of an iceberg is below the water line and, therefore, potentially a better target for remote detection using sonar.

However, the use of sonar in this role is not without problems. From a technological point of view, little information concerning icebergs as individual sonar targets exists in the public domain. Also near surface horizontal acoustic propagation in the ocean is subject to refraction phenomena and the effects of waves and turbulence. From an engineering perspective, the installation and eventual deployment of a sonar transducer system within the bow area of an icebreaking hull is not trivial. Therefore, any program which attempts to address some of the above aspects is important in that it should provide useful basic design information concerning the feasibility and practicality of using sonar for iceberg detection.

1.2 THE PROOF OF CONCEPT TESTS - OBJECTIVES

The primary objective of the trials described in this report is to evaluate the potential of using a sonar system installed in the commercial ice breaking freighter, the MV Arctic, as a means of detecting icebergs. The use of a large commercial ocean going vessel chartered specifically for this purpose would be outside any reasonable non-military budget. Thus, an alternative approach involving the allocation of a certain period of time during a normal commercial voyage of such a vessel appears to be a more cost effective solution.

The Proof of Concept Tests attempts to provide the client with:

1. A preliminary assessment of the detectability of ice hazards by means of a ship-mounted sonar.

2. A phenomenological model which relates the iceberg's ability to reflect sonar signals with the physical characteristics of selected target icebergs.

The overall project consisted of several phases:

Phase One - The evaluation and selection of a suitable commercially available sonar system.

Phase Two - The installation and calibration of the sonar system on the icebreaking freighter MV Arctic, together with the design and realization of the data acquisition system.

Phase Three - Data acquisition from selected icebergs.

Phase Four - Evaluation and assessment of the collected data.

The timing of the above program was controlled by the commercial scheduling of the MV Arctic. The data acquisition phase required the ship to be enroute between ports of call in an area where icebergs are known to exist. A possible period for these trials to take place occurred at the beginning of 1984 Arctic shipping season when the MV Arctic was scheduled to sail from Antwerp, Belgium to Nanisivik to load ore. As the routing of the ship included a passage up the west coast of Greenland, the availability of icebergs at this time would not present a problem. The timing of the data acquisition phase meant that the selection of the equipment and its installation would have to be complete before the MV Arctic left Canada for European waters. Also, limited time allocated to these trials mean that all equipment would have to be operational and all procedures finalized before the MV Arctic entered the Labrador Sea. In addition, a preliminary data analysis would have to be undertaken during the data collection phase in order to ensure data quality. Thus, equipment and personnel would have to be available on board ship to enable preliminary results to be computed.

2.1 GENERAL DESCRIPTION

Icebergs and sea ice represent the major hazard to Arctic navigation. Most icebergs found off eastern Canada calve from the glaciers on the south and west coasts of Greenland and drift north in the West Greenland Current. The icebergs often remain in the Baffin Bay region for several years before heading south along the Labrador coast under the influence of the Labrador Current. Since icebergs are continually melting due to the action of waves and increases in water and air temperatures, they naturally change shape. This melting process is non-uniform. Therefore, icebergs periodically become unstable and either roll or break up into smaller pieces. Icebergs can range in size from ice pieces several metres in length to icebergs with dimensions in excess of 200 metres and masses greater than 10 million tonnes. Maximum keel depth of these very large icebergs can exceed 200 metres. On the other hand, sea ice is formed by the freezing of the ocean and can form ridges with sail heights up to 30 metres and draughts in the order of 40 metres. On melting, these ridges break up and become small hazards.

As icebergs drift into shallow water, they often become grounded and can remain stationary for long periods. Eventually, however, when suitable conditions prevail, they will move off and continue their course. Both icebergs and sea ice present a threat to safe navigation in Arctic waters.

2.2 ICEBERG TYPES

The International Ice Patrol has a classification scheme that groups icebergs into shape and size categories based on their above water dimensions. This classification scheme is given in Table 2-1 along with approximate details on the sizes of typical icebergs in each category. It is used by most ice observers and interested parties for recording iceberg details. Of great interest to commercial organizations, in particular oil companies with drilling programs in Arctic areas, are estimates of mass and the maximum depth of the keels. Using presently available technology,

ICEBERG CLASSIFICATIONS TAKEN FROM INTERNATIONAL ICE PATROL GUIDELINES

ICEBERG TYPE CLASSIFICATIONS

NAME	I.D. CODE	DESCRIPTION
Blocky	BL	Steep precipitous sides with horizontal or flat top. Very solid berg. Length/height ratio 5:1 approx.
Drydock	DD	Eroded such that a large U-shaped slot is formed with two columns of pinnacles. Slot extends into the waterline or close to it. Last stage of drydocked bergs are horned and arched.
Dome	DO	Large smooth rounded top. Solid type berg.
Pinnacled	PI	Large central spine or pyramid or one or more spines dominating the shape. Less massive than dome-shaped bergs of similar dimensions. These are also known as Picturesque "Greenland" type bergs.
Tabular	TA	Horizontal or flat-topped berg with length/height ratio of 5:1 (approx.).
Berg, Bit	BB	A mass of glacial ice smaller than berg but larger than a growler, about the size of a small cottage. Small berg or large growler is preferred usage.
Growler	GR	A mass of glacial ice that has calved from a berg or is the remains of a berg. Less than 1.5 m in height and less than 6.0 m waterline length

ICEBERG SIZE CLASSIFICATIONS

Type	I.D. CODE	HEIGHT	LENGTH
Tabular Bergs:			
Small	S	5 m	Less than 90 m
Medium	M	5 - 15 m	90 - 215 m
Large	L	Greater than 15 m	Greater than 215 m
Other Bergs:			
Small	S	Less than 15 m	Less than 60 m
Medium	M	15 - 45 m	60 - 120 m
Large	L	45 - 75 m	120 - 215 m
Very Large	V	Greater than 70 m	Greater than 215 m

TABLE 2.1: ICEBERG CLASSIFICATIONS

measurement of above water dimensions of icebergs under normal conditions is reasonably accurate but underwater measurements on a routine basis are subject to gross uncertainties. Estimates of iceberg mass are relatively easy if volume is known (see Appendix I). Iceberg volume is easily obtained from accurate above water dimensions and/or three-dimensional photography, albeit at some cost. However, every iceberg has a unique underwater shape and thus far, routine mapping of underwater shape is not economically viable. Nevertheless, over the last few years, several research programs mainly in support of oil drilling activities have used sidescan sonar technology to provide the underwater shape of icebergs. Klepsvik and Fossum (1980) have described the method commonly used for this work and Lowry et al. (1979) and Benedict and Hall (1979, 1980) have reviewed most other sonar techniques. Figure 2.1 is an example of two vertical underwater profiles taken of a large iceberg off Labrador. Although not to scale, the approximate underwater shape can be seen. Figure 2.2 is an interpretation of the overall shape when all data is included. These figures, presented by kind permission of PetroCanada Inc., indicate the most common features of all icebergs namely that the underwater dimensions are greater than surface measurements, that a bulge, or "indentor", exists and that the underwater shape is complex. Only in the last two years have attempts been made to produce three-dimensional maps of the underwater shape of icebergs. This research is certainly in its infancy and presently these data are proprietary.

In summary, therefore, it is reasonable to assume that as sonar targets, icebergs will exhibit a great range in magnitude due to several factors including size, shape and aspect. Since historical information on the target characteristics of icebergs is to all intents and purposes nonexistent, any program that attempts to evaluate icebergs as remote targets must be considered an important event in sonar technology.

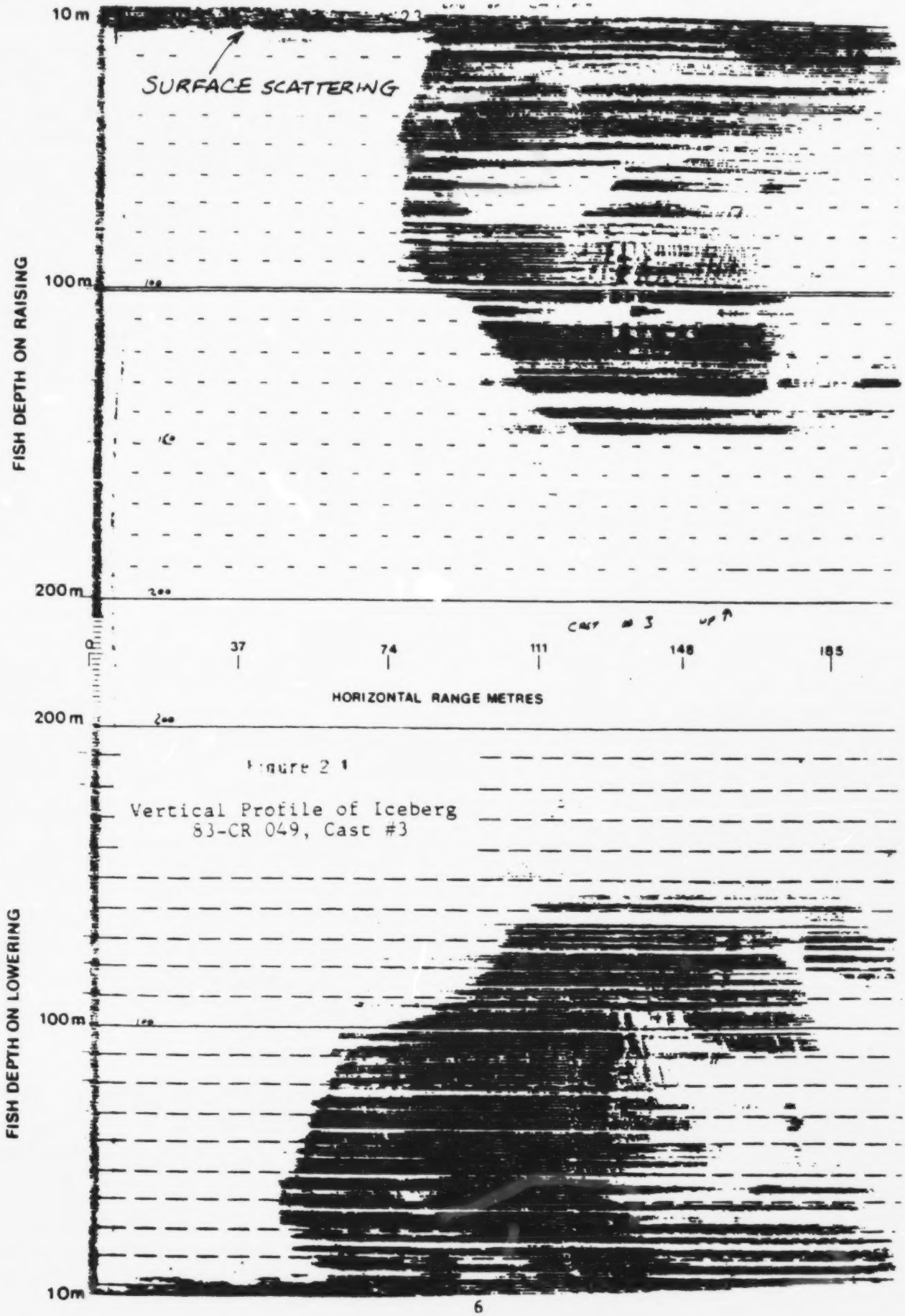
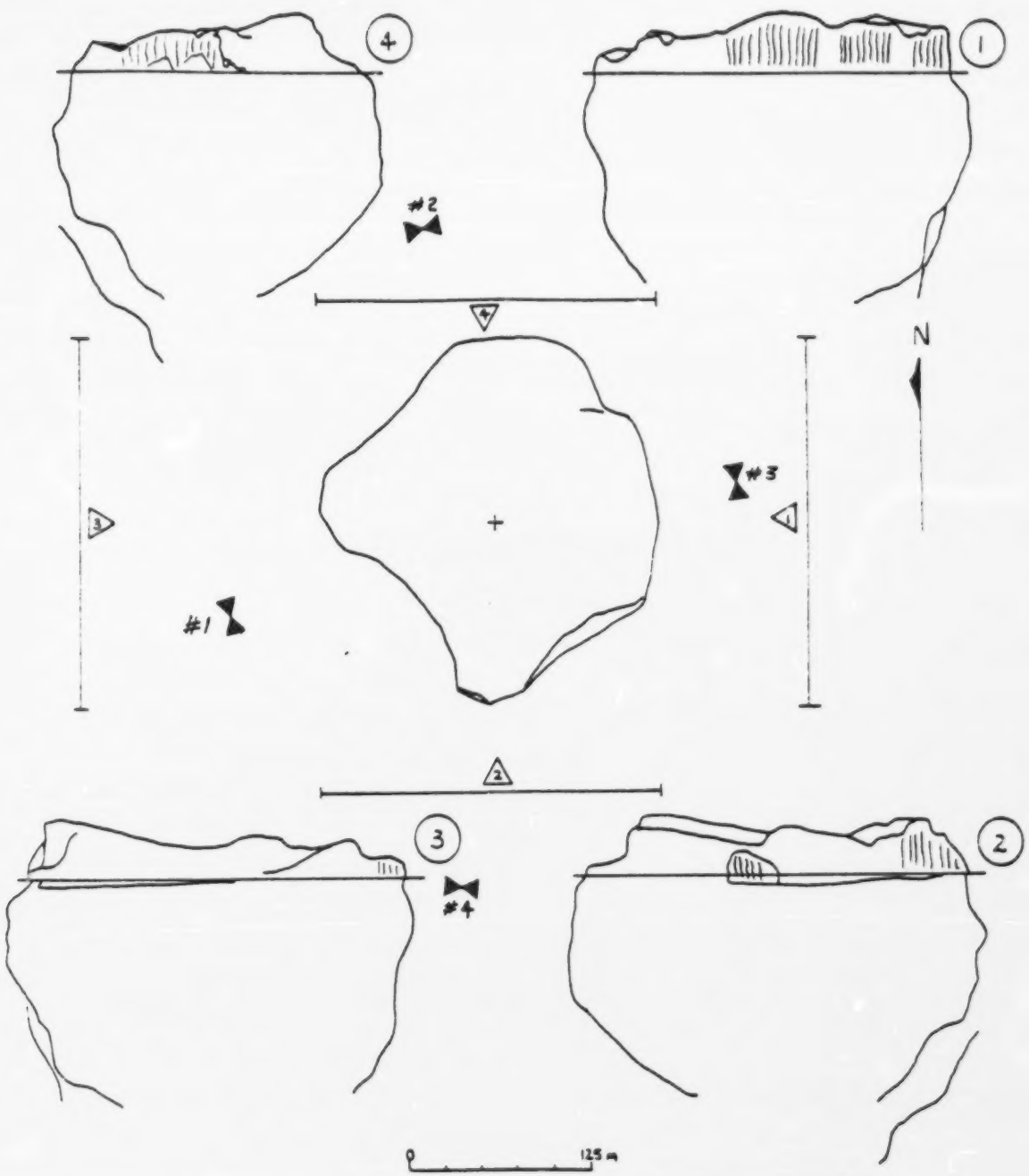


Figure 2.1

Vertical Profile of Iceberg
83-CR 049, Cast #3



Geomarine Associates Ltd. St. John's Newfoundland

Iceberg Surveillance Program 1983 Client Petrocan

Wellsite CORTE REAL Iceberg Type BLOCKY Date 22 JULY 83

Length 250 m. Width 130 m Height 37 m Draft 135 m

Mass 5364 k tonnes Comments:-

Figure 2 2: OVERALL SHAPE INTERPRETATION

2.3 THE ICEBERG AS A SONAR TARGET

The technique of classifying underwater objects as targets has its roots in the military establishment. The physical principle on which this type of remote sensing relies is that a target illuminated by a sonar beam will intercept acoustic energy and redirect it in all directions. Under normal conditions, some of this energy will be reflected back towards the source and could be detected as an echo by a suitable receiver. The time interval between the original outgoing pulse and the arrival of the echo is obviously a function of the distance between the target and the source. Since the sound speed in water is known, target range is easily calculated. The amplitude of the echo should also be expected to be some function of the amount of energy intercepted and redirected by the target. Target size, its reflecting qualities and its geometry could, therefore, contribute to echo generation. In other words, the potential exists for the amplitude of the echo to be an estimator of the physical size of the target. If icebergs were perfect geometrical shapes and transmission of acoustic energy in water were not affected by the characteristics of the medium then the relationship between echo amplitude and target size would be well controlled. However, nature is such that this situation rarely exists. Icebergs do vary considerably in shape, and convex and concave surfaces can produce defocusing and focusing zones which will have a considerable effect on echo amplitude. Also, the reflecting qualities of ice vary considerably with temperature particularly around the freezing point. Fortunately, the mass of an iceberg is such that the temperature of the ice surface is likely to be reasonably stable. All these factors will tend to mask amplitude effects due to size alone.

Another important factor that does not affect amplitude directly but must be considered in any underwater propagation problem concerns the changes in sound speed characteristics of the ocean. Changes in pressure, salinity and temperature will result in sound speed variations causing acoustic paths to refract. This has the effect of creating shadow zones even over short ranges, Urick (1975). One final propagation problem likely to be encountered is the effect of turbulence and wave action close to the sea surface. Since a ship-mounted sonar would invariably involve

transmission paths just beneath the sea surface, these effects could degrade and mask target echoes due to scattering and sea noise. Figure 2.1 shows this effect at transducer depths less than 10 metres.

2.4 THE CONCEPT OF TARGET STRENGTH

In active sonar systems where echoes are used in a quantitative sense as well as being a range estimator, the echo amplitude has in some way to be referred to the target object. The most common method of making this transition is to invoke a concept of target strength such that the energy contained in an echo in some way reflects a target size parameter.

This can be accomplished by referring the energy contained in an actual echo to that which would result from a target sphere of standard dimensions and composed of perfectly reflecting material. Sonar engineers have found that by assuming a standard spherical target with a radius of two metres, the target strength of a uniform sphere equals:

$$\text{Target Strength} = 20 \log \frac{a}{2} \quad \ldots\ldots \quad 2.1$$

where a is the radium of the sphere in metres.

For complex targets:

$$\text{Target Strength} = 10 \log \frac{\sigma}{4\pi} \quad \ldots\ldots \quad 2.2 \text{ (Urick, 1975)}$$

where σ (m^2) is the effective scattering cross section.

Target strength of a remote object can only be calculated if the sonar transducer parameters are known and if the entire sonar system is calibrated. Appendix II describes the usual method of including the system parameters in the estimation of target strength. In most sonar work, it is assumed that the echo from the target occurs at a single point in space and

the form of the echo will be that of the transmitted pulse. With large targets, as in the case with icebergs, this is not the case. As discussed in Section 2.3, an iceberg could present many individual facets (targets) at various ranges. Thus, the echo is likely to be random in both amplitude and time of arrival and not truly representative of a classical echo from a standard target. One method of compensating this effect to a first order approximation is to integrate the energy over the total period of the echo and then compare the result with an integral of an idealized transmitted waveform. This process was applied in target strength estimates obtained from these trials to supplement estimates of target strength using a peak energy criterion. In the remainder of this report, the "integral" target strength is termed "total", whereas the "peak" target strength is denoted as such. Appendix II reviews these two methods.

2.5 OTHER EFFECTS

The sonar equation developed in Appendix II indicates that for a particular iceberg, the target strength should be independent of range. However at close range, only a small portion of the iceberg will be illuminated. In addition, an ice/water interface is not a perfect reflecting surface. This suggests that differences will exist between a theoretical model and the actual situation. Figure 2.3 is the computed target strength versus range for a rough ice surface using an interface loss of -20 db. At larger ranges where more of the target is illuminated, target strength increases towards a limiting value. Conversely at close ranges, the target strength is much lower than theory predicts. Compensation for this loss in target strength could be applied to large icebergs measured at short ranges.

2.6 STATISTICAL CONSIDERATIONS

From classical detection theory (e.g., DiFranco and Rubin, 1969), it is well known that the character of the fluctuations of radar and sonar targets is an important factor in the design and performance assessment of detectors for these targets.

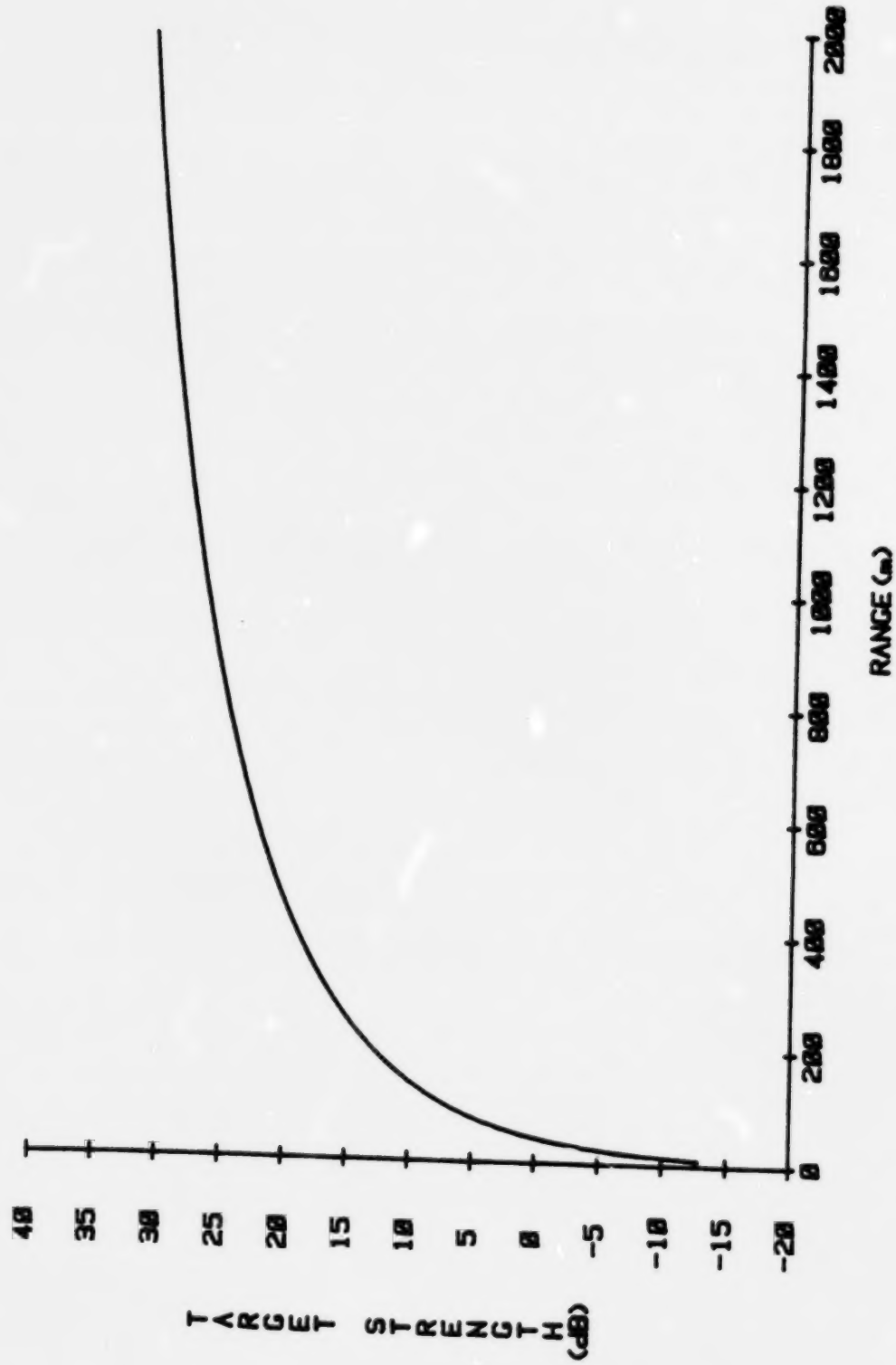


Figure 2.3: TARGET STRENGTH VS. RANGE FOR A SOLID WALL OF ICE

In the particular case of the target strength which is of concern here, the following parameters have been used to characterize the fluctuations.

Mean:	The average value of the target strengths obtained for a given target (or a given run). This set of observations is referred to as the population.
Standard Deviation:	Most probable distance from the mean in the population considered.
Median:	Value such that an equal number of individuals in the population are greater and smaller than this value.
10 - Percentile, (90 - Percentile):	Value such that 10% (90%) of the population are below it and 90% (10%) are above it.
Exponential Distribution:	A statistical distribution characterizing a large class of sonar targets made of unresolved scatterers. It is characterized by the fact that its standard deviation is equal to its mean.

Defining the precise significance of these concepts is outside the scope of this report. The interested reader is referred, for more details to any standard text on detection such as, eg. DiFranco and Rubin, 1969, or, at a more basic level, Urick, 1975.

3.1 PROJECT CONSTRAINTS

The project's two principal goals include the assessment of iceberg detectability and the derivation of a phenomenological model relating measured target strength of icebergs to their mass. Early in the planning stages of this project, it was recognized that in order to achieve these goals during the 1984 commercial shipping season, a sonar system had to be procured rather than developed. The time constraints dictated that a fish finding sonar was probably the only option in fulfilling these requirements. In discussions with various manufacturers and the contractor, Canarctic decided that within the time available, the C-Tech CDS-40A sonar system offered the most cost effective solution. In these discussions, it was recognized that the characteristics which qualify a sonar for iceberg detection are not necessarily those that make it ideal for calibrated acoustic measurements. For example, automatic gain control is unacceptable where amplitude measurements are concerned whereas, for detection, this technique is advisable. Also for the detection of small targets at long ranges, a narrow beam width is an advantage whereas in making observations of icebergs at close ranges, a wide beam is more appropriate.

The choice of the C-Tech CDS-40A sonar led to further sonar related constraints.

1. The CDS-40A operates at one frequency only, therefore, measurements over a range of frequencies would not be possible.

2. The CDS-40A is not normally supplied for use in experimental procedures involving accurate amplitude observations. Thus, operator controls were not of a type ideal for precise measurement.

In addition, the trials had to be undertaken during the summer season when surface water temperature refracts sound downwards.

Several other constraints are inherent in the use of a large commercial vessel such as the MV Arctic for conducting sea trails. Manoeuvrability is an obvious restriction even in open water so that test runs which involved circling target icebergs had to be undertaken with great care. Also as the ship was operating under a commercial charter, it was imperative that all trials be conducted within the allocated time period.

3.2 EQUIPMENT

3.2.1 THE C-TECH CDS-40A SONAR

The CDS-40A sonar is normally supplied as a fish finding sonar system. The system comprises a transducer assembly mounted beneath the hull and a control and display unit mounted on the bridge. The CDS-40A sonar transducer transmits an omni-directional, 36 kHz cw pulse of known amplitude and duration. Its receiver has a vertical combined transmit/receive "audio" beamwidth of 13° and a horizontal "audio" beamwidth of 17°. These and other sonar characteristics are described more fully in the C-Tech Report #764 (see Appendix III). The sonar transmitter was mounted through a gate valve approximately 30 metres from the bow and directly below the forward crane (see Figure 3.1). Transducer calibration information is given in Appendix III.

3.2.2. THE DATA ACQUISITION SYSTEM

The layout of the data acquisition system is shown in Figure 3.2. The received echo is amplitude modulated on a 1 kHz carrier and transmitted to the CDS-40A controller on the bridge via a co-axial cable. The signal is then demodulated and displayed on the television monitor in the standard PPI format. An operator-controlled cursor can be used to select the bearing of the target whose unprocessed echo can be monitored at the "audio" output connector. This "audio" signal is digitized by the Data 6000 Waveform Analyzer and also recorded by the B&K analogue tape recorder.

FIGURE 3.1

POSITION OF SONAR TRANSDUCER

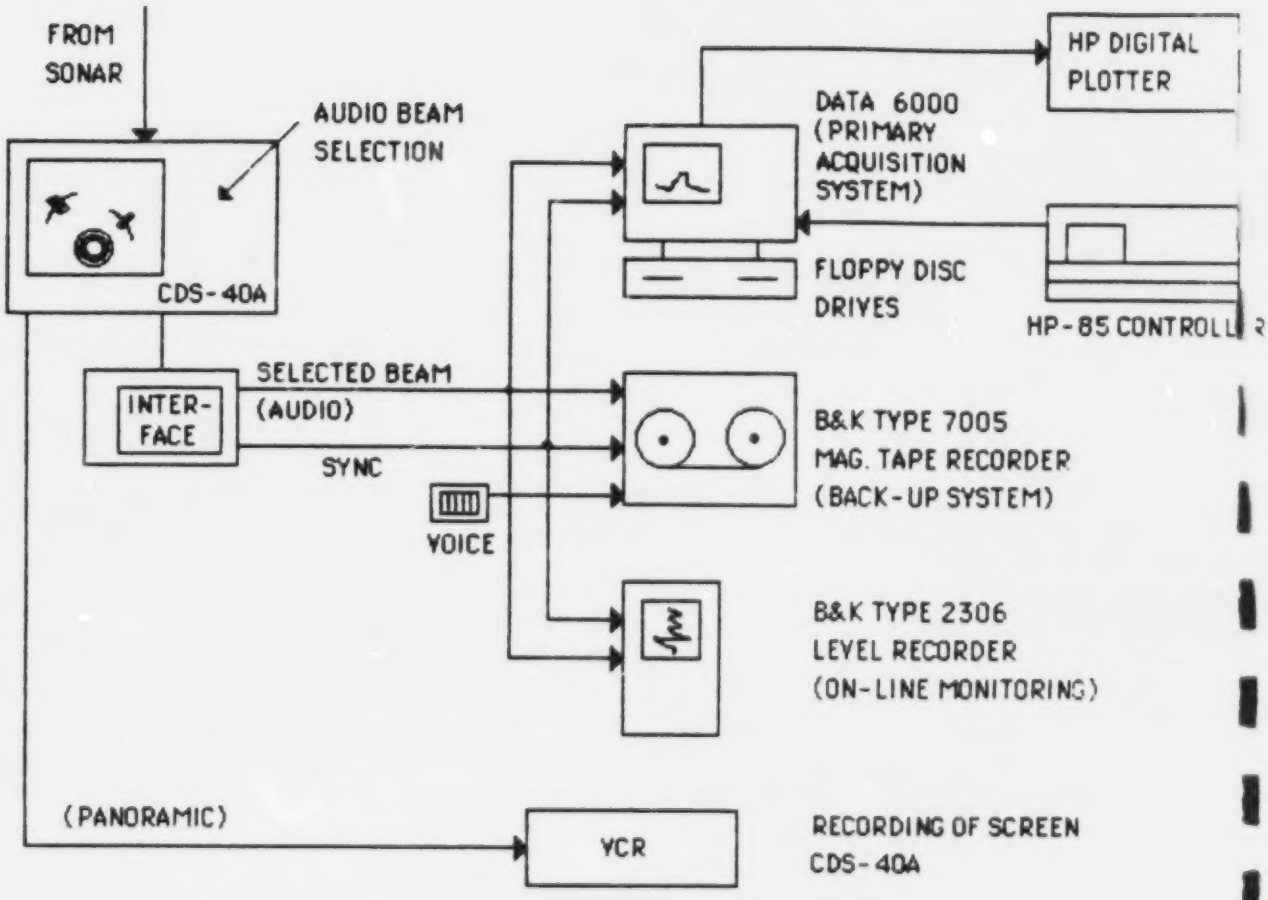


FIGURE 3.2.

DATA ACQUISITION FLOWCHART

3.3 DATA ACQUISITION

The data acquisition procedure involves the identification of the particular echo on the CDS-40A display and positioning the cursor as described above. The process of identifying the iceberg is critical to the whole procedure and is accomplished under manual control. The following list describes the use of the primary controls of the CDS-40A Display unit:

Power Level - The amplitude of the transmitted pulse is adjusted so that the return echo is visible on the CDS-40A monitor and the level recorded on the audio channel is less than 5 volts (peak to peak).

Cursor - The cursor, a small white square visible on the PPI display is positioned by a joystick to the same bearing as the echo of interest.

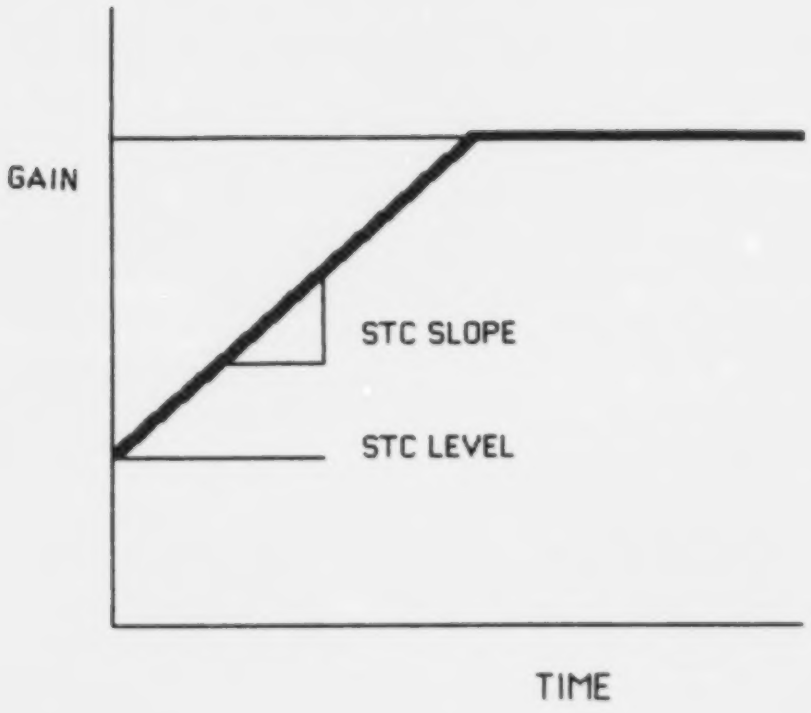
STC Slope, Level and Gain - These three controls affect the sensitivity of the sonar receiver. Since the amplitude of the echo received from a target diminishes with range, compensation in the form of a time varying gain function can be applied.

The net effect is to produce an echo whose intensity is nominally independent of range. Figure 3.3 is an illustration of receiver sensitivity versus time showing the physical definition of each of these parameters.

Dwell - Controls the repetition rate of the sonar pulses.

Tilt Angle - The "look direction" of the sonar transducer is electronically variable from 0 to -45° in the vertical plane. The tilt angle determines this direction.

Width - Controls the duration of the pulse transmitted by the sonar.



AUTOMATIC GAIN CONTROL
SETTING DEFINITIONS

FIGURE 3 3 AUTOMATIC GAIN CONTROL SETTING DEFINITIONS

All these parameters are set by potentiometers on the front panel of the CDS-40A. This operation presented some difficulty during the actual data acquisition since changes in the relative position of the ship and target demanded that these controls be continuously adjusted. Although the potentiometers were graduated, it is possible that setting errors were introduced. These errors are felt to be mostly small. The potentiometer settings were logged during the data acquisition and ultimately used in the target strength calculations.

3.4 DATA RECORDING

The primary recording instrument for the echoes was the Data 6000 Waveform Analyzer. As a result of input rate limitations, the Data 6000 recorded one out of every four echoes. In order to avoid errors, automatic control of the recording process was provided by the HP 85 Microcomputer. A two second data file with a sampling rate of 5 kHz was recorded by the Data 6000 Analyzer following a trigger pulse from the CDS-40A controller. For permanent storage, each data file was stored on floppy disc under a "filename" with the following format:

Dddhhmms.DAT

where dd = date
hh = hours (G.M.T.)
mm = minutes
s = decimal minutes

The CDS-40A controller settings and other relevant information were recorded in the log books.

3.5 FIELD PROGRAM

The field trials involved manoeuvring the MV Arctic in close proximity to selected icebergs and recording sonar echoes continuously. Five different types of manoeuvers were planned in order to collect sonar information over a comprehensive program of ranges, iceberg sizes and target directions. These manoeuvers, or "runs" consisted of:

Run Type ALPHA - Vessel standing by, icebergs drifting.
Run Type BRAVO - Vessel circling target iceberg.
Run type CHARLIE - Radial run, passing close to target.
Run type DELTA - Data collection, vessel underway.
Run type ECHO - Noise measurement, vessel underway or hove to.

Iceberg size was estimated by photographic techniques using the horizon as a reference as well as by the ice observers.

The actual trials took place off the west coast of Greenland between July 28, 1984 and August 1, 1984. A total number of 14 icebergs were measured each involving several run types. A short diary of events is given in Appendix IV. The data collected during these trials was examined on board and a preliminary analysis performed. Sound speed profiles of the water column were obtained at regular intervals using the Sippican XBT (Expendable Bathythermograph) system in order to compute the propagation characteristics. This system proved unreliable and the cause was not determined during the course of the trials*.

On completion of the trails, the MV Arctic continued the voyage to Baffin Island and arrived in Arctic Bay on August 2, 1984. The scientific and technical personnel left the vessel at Nanisivik and returned to Ottawa via Frobisher.

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*Most probably mechanical wear of launching assembly or defective probes.

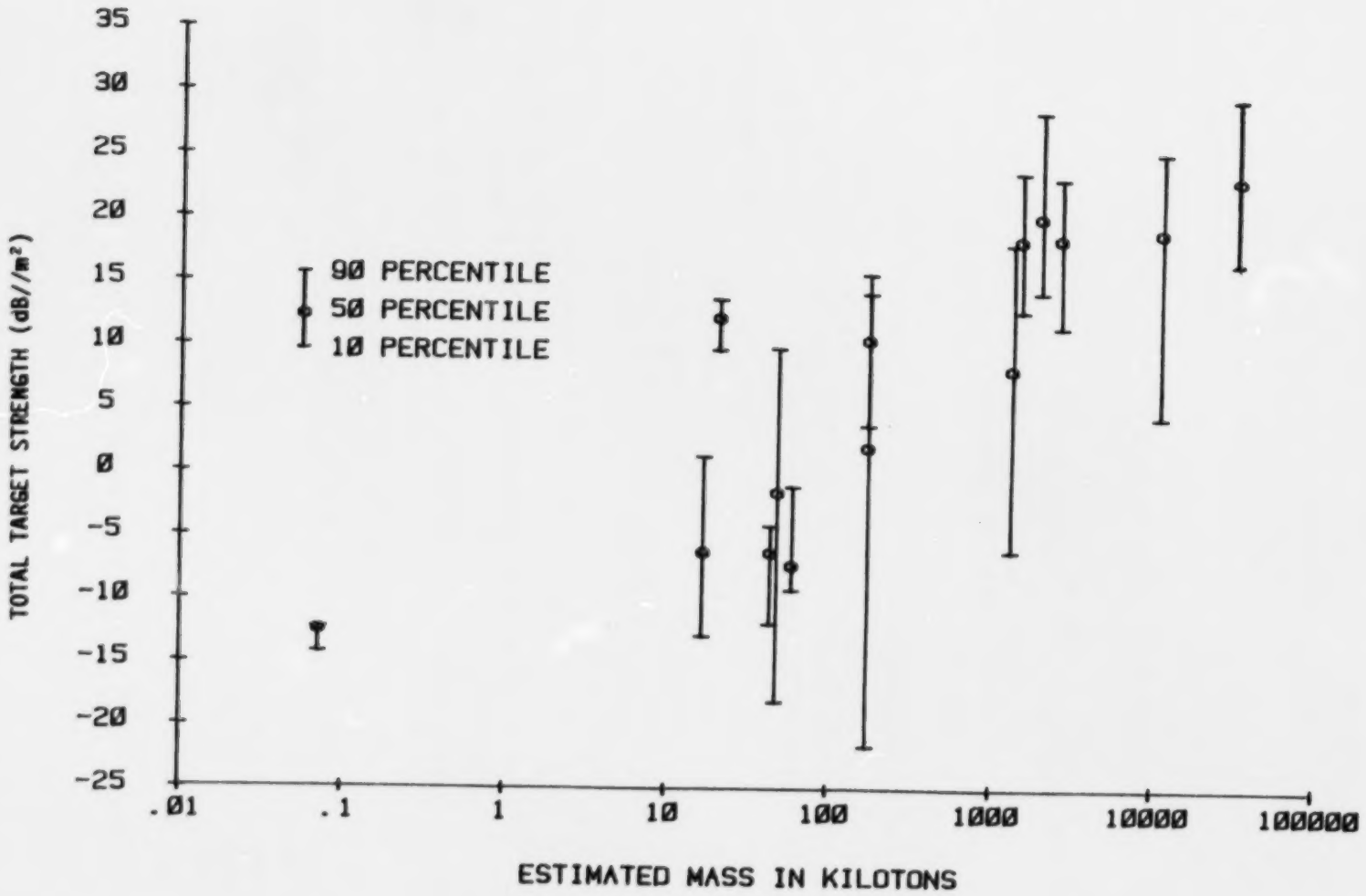
4.1 PRESENTATION OF RESULTS

In total 1161 sonar echoes were recorded from 14 different icebergs. Average Target Strength estimates for each echo were computed using both the peak energy criterion within an 8 ms window ("peak target strength") and the integrated energy ("total target strength") method. The first stage in processing the recorded data involved locating the target echo within the two second data file stored on disc. This procedure entailed printing a hard copy of each echo and visually selecting the desired target.

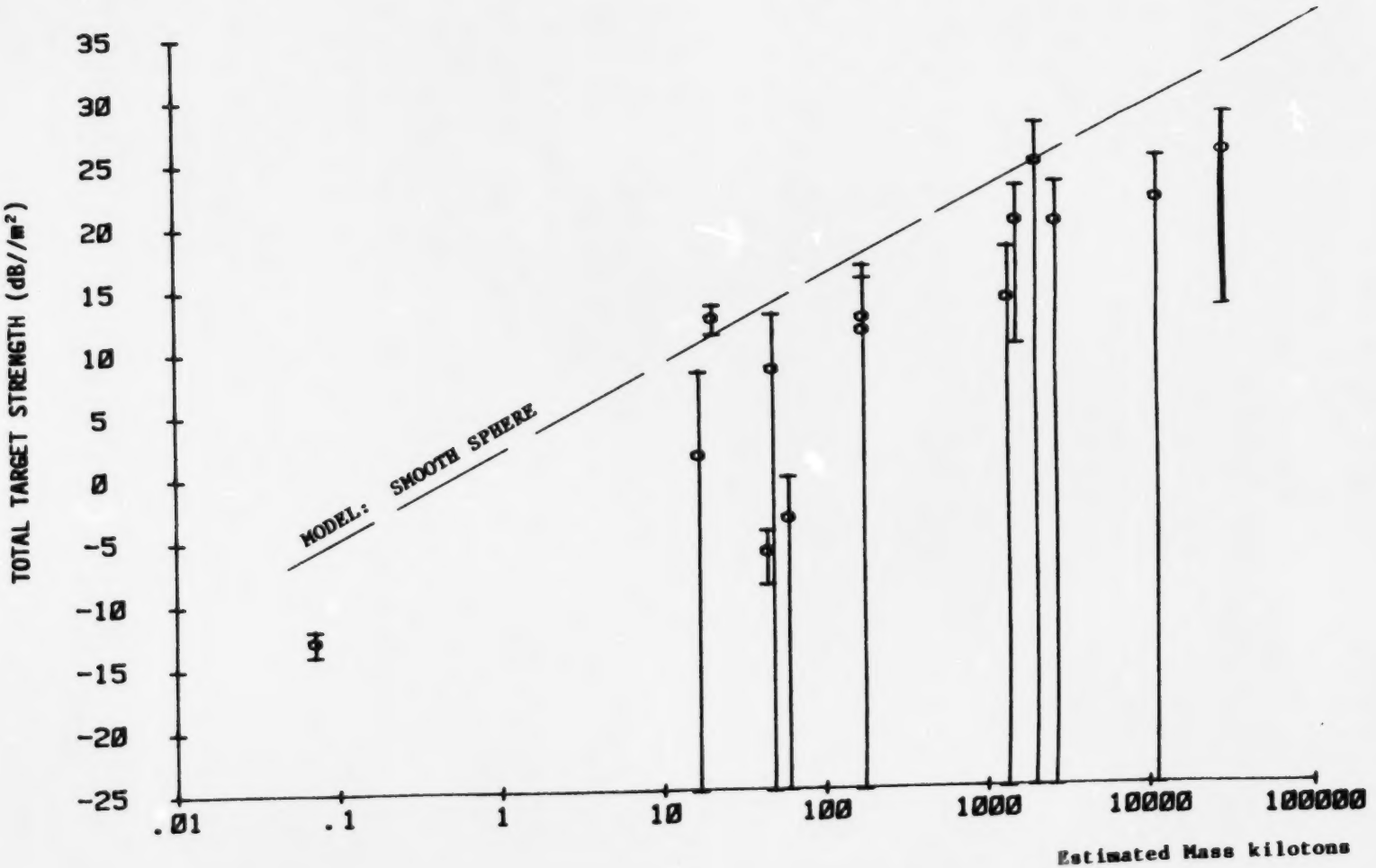
Information sheets, photographs and examples of the processed echoes for all the target icebergs are collated in separate files in Appendix V. The variation in target strength of each iceberg is presented as a histogram and is also included in this Appendix.

Figure 4.1 summarizes the target strength measurements versus iceberg mass for all 14 icebergs. In this data set the bars indicate range in the target strength estimates (dB) between the 10th and 90th percentile of the distribution. No attempt has been made to compensate for underwater shape, propagation conditions, sonar orientation or for the range effect discussed in Section 2.5. Although a general trend in the data suggests that target strength increases with mass, the spread in the estimates are large, probably due to combination of the factors mentioned above.

The target strength estimates are presented in Figure 4.2 as the mean value of all measurements prior to converting to the logarithmic form with the range bars representing one standard deviation. This method of computation appears to offer a more linear relationship between the mean values for target strength and the estimated mass than that shown in Figure 4.1.



TOTAL TARGET STRENGTH AS A FUNCTION OF ESTIMATED MASS FOR 14 ICEBERGS, REPRESENTED IN TERMS OF MEDIAN, AND 90-, 50-, AND 10-PERCENTILES



TOTAL TARGET STRENGTH AS A FUNCTIO OF ESTIMATED MASS FOR 14 ICEBERGS, REPRESENTED IN TERMS OF MEAN AND STANDARD DEVIATION OF THE LINEAR VALUES, CONVERTED TO DECIBLES

Figure 4.3 shows the echo duration against estimated mass for all the measured icebergs. Again a large spread in the data sets is observed. Of particular interest is the fact that icebergs with estimated mass between 20 k tonnes and 200 k tonnes display the greatest variability. As with the target strength estimates, no adjustments have been made to correct for environmental or target related effects.

A sequence of target strength histograms for 5 categories of bergs (see Appendix I) are presented in Figure 4.4. The estimated mass of these icebergs range from 115 tonnes to approximately 15 million tonnes. The histograms from the four largest iceberg classes a significant spread in average target strength. However, the number of samples in each case is statistically significant which gives confidence in the distributions obtained. In the measurements on the small growler, only three estimates of target strength were obtained indicating that these data may not be significant.

Figure 4.5 shows the maximum observed reliable detection range from all the type Alpha and Charlie runs made on the selected icebergs. Again no compensation for range or environmental conditions have been applied.

4.2 INVESTIGATIONS INTO THE LIMITS OF PERFORMANCE

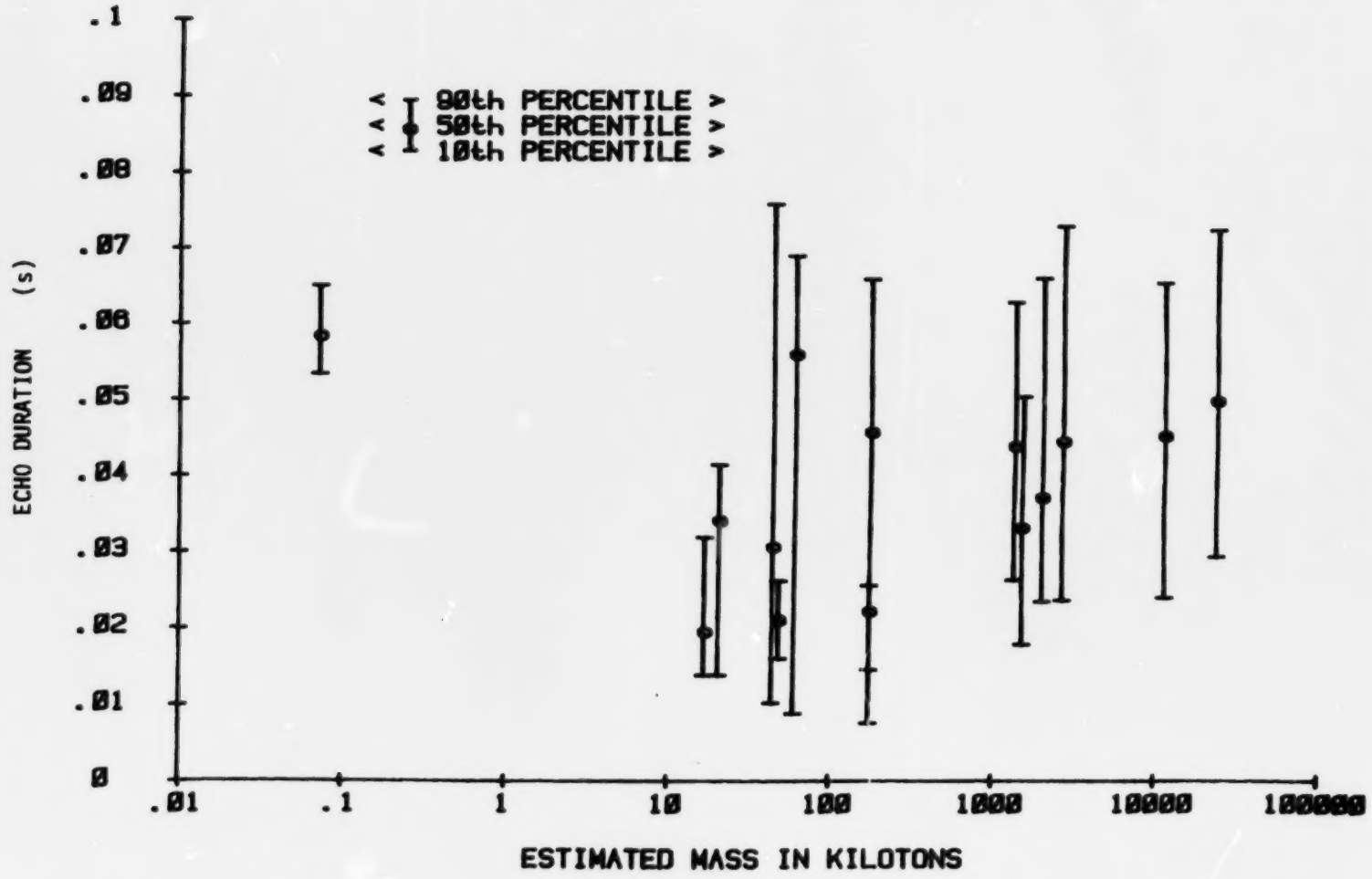
The analyses performed on the recorded data have been aimed at quantifying and evaluating those physical properties which determine the limits of performance of an optimized ice detecting sonar.

Three performance criteria were investigated:

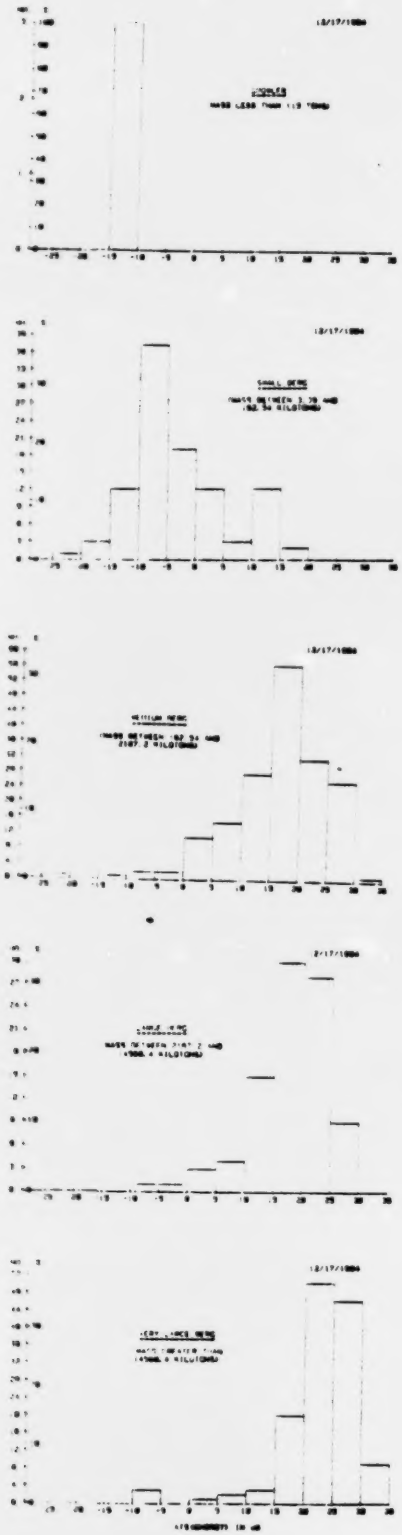
1. Limitations in performance due to the characteristics of icebergs as sonar targets.

2. Limitations in performance due to the sound propagation characteristics in Arctic waters.

3. Limitations in performance due to background noise interference.



ECHO DURATION STATISTICS AS A FUNCTION OF ESTIMATED MASS
FOR 14 ICEBERGS



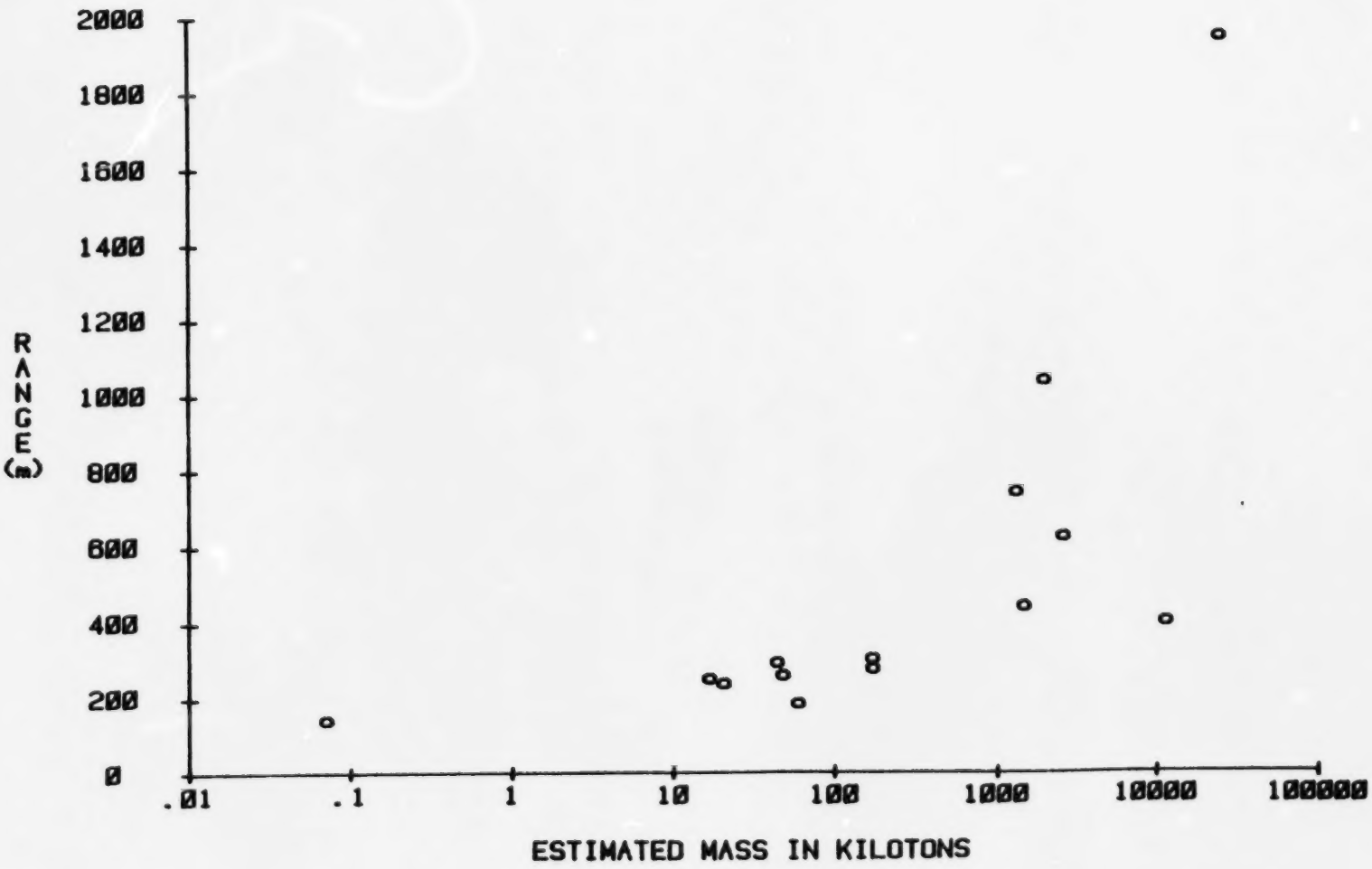


FIGURE 4. MAXIMUM OBSERVED DETECTION RANGE VS. ESTIMATED MASS

The performance limitations due solely to the characteristics of the icebergs are inherent in the relationships shown in Figures 4.1 through 4.5 and in the data files in Appendix V. The obvious relationships between target strength and size have been discussed earlier, however since echoes have little resemblance to the outgoing pulse shape, some time-related feature must be involved. The echo duration is an indicator of the time interval over which the iceberg reflects echoes and therefore is related to the various ranges of the echoes from the many reflecting surfaces. For the larger icebergs the echo duration is approximately 50 ms indicating range differences in the order of 20 metres. This suggests that a large portion of the surface of the icebergs is illuminated.

4.3 PERFORMANCE LIMITATIONS DUE TO PROPAGATION CHARACTERISITCS

Under ideal conditions, reflective properties of targets estimated using the target strength parameters should be independent of range. If the echo parameters remain constant then any departure from this range independence indicates that other processes are affecting target strength. Since sound attenuation in sea water is not seriously affected by environmental conditions, the most important factor (other than the effect discussed in Section 2.5) that could effect transmission is the anomaly caused by ray bending. These transmission anomalies can be readily displayed if target strength is plotted against range.

Where available these data have been plotted for the icebergs evaluated in the trials. The resulting graphs are presented in Appendix V. The general tendency is for the target strength to increase between 10 dB and 20 dB over the range interval 100 to 1400 metres. However the small iceberg, #14, shows the opposite effect. For the larger icebergs, the observed increase may be due to the range effect described in Section 2.5. This could more than compensate for a possible transmission anomaly that would invariably cause a decrease with range.

In fact, at the time of detailed data analysis, it was recognized that the limitations inherent to the data acquisition runs precluded any sorting out of the two effects. Another indication of the combined effects of range, propagation and shape on target strength is given in the Appendix V diagrams displaying for several Bravo runs, the estimated target strength as a function of aspect and range.

Other graphs available in Appendix V include maximum range and target strength relationships with sonar azimuth. These data sets have been supplemented with ray path and transmission loss diagrams computed from sound velocity profiles. The latter are presented in Appendix VI. The information they give is more qualitative than quantitative, because of the variability of the medium and the unavailability of the XBT mentioned above.

4.4 PERFORMANCE LIMITATIONS DUE TO BACKGROUND NOISE

The detectability of a sonar signal is partially determined by the ratio of the signal level to the background noise within a known bandwidth. In the case of an active sonar, the returned echo must be detectable over noise produced by a variety of natural sources as well as sound reflected from objects or surfaces other than the target itself. The amount of "reflected" noise from objects in the water, the sea surface and the sea floor is to some degree a function of the beam pattern and bandwidth of the sonar, and its mode of operation. The natural noise sources however, produce a quasi-steady state background level which will degrade and ultimately limit the performance of all sonar systems. For these reasons, it is desirable to make specific measurements of noise under a variety of operating conditions.

Noise measurements made during the trials with the MV Arctic were performed with the vessel both at shallow and at icebreaking draught. It was originally intended to measure the noise level during ice breaking activities, but unfortunately the added risk of damage prevented these measurements from being made. Listening at the bow during ice breaking revealed only low frequency (around 100 Hz) noise components. It is therefore not very likely that icebreaking would affect the noise background around 40 KHz very significantly.

The CDS-40A was set up for noise measurements by reducing the transmitted output power to zero. This mode of operation effectively reduced the sonar to a passive, listen, only, mode.

Figures 4.6 and 4.7 summarize the noise results for the two experiments and show Background noise level within the bandwidth of the receiving system (2000 Hz). Of interest is the fact that the speed of the vessel has little overall effect on the noise level except that at 10 knots the noise level is generally higher than at 15 knots. Over the azimuth range of 30, the noise level in shallow draught is between 12 dB and 15 dB greater than at ice breaking draft. Also noise level tends to increase with azimuths of +90 and -90. In this investigation no serious attempts to separate ambient sea noise from ship generated self noise were made.

4.5 A PHENOMENOLOGICAL MODEL OF ICEBERG TARGET STRENGTH

Although a statistically significant number of echoes were obtained from most of the icebergs studied in the trials, the actual number of data sets is relatively small. In addition, mass estimates are based on visual observations of surface dimensions only. These two basic features and the relatively non-uniform target shape means that any relationship between an acoustic and physical parameter will be subject to large uncertainties. Nevertheless, sufficient data was collected which enabled a relationship between target strength and iceberg mass to be derived.

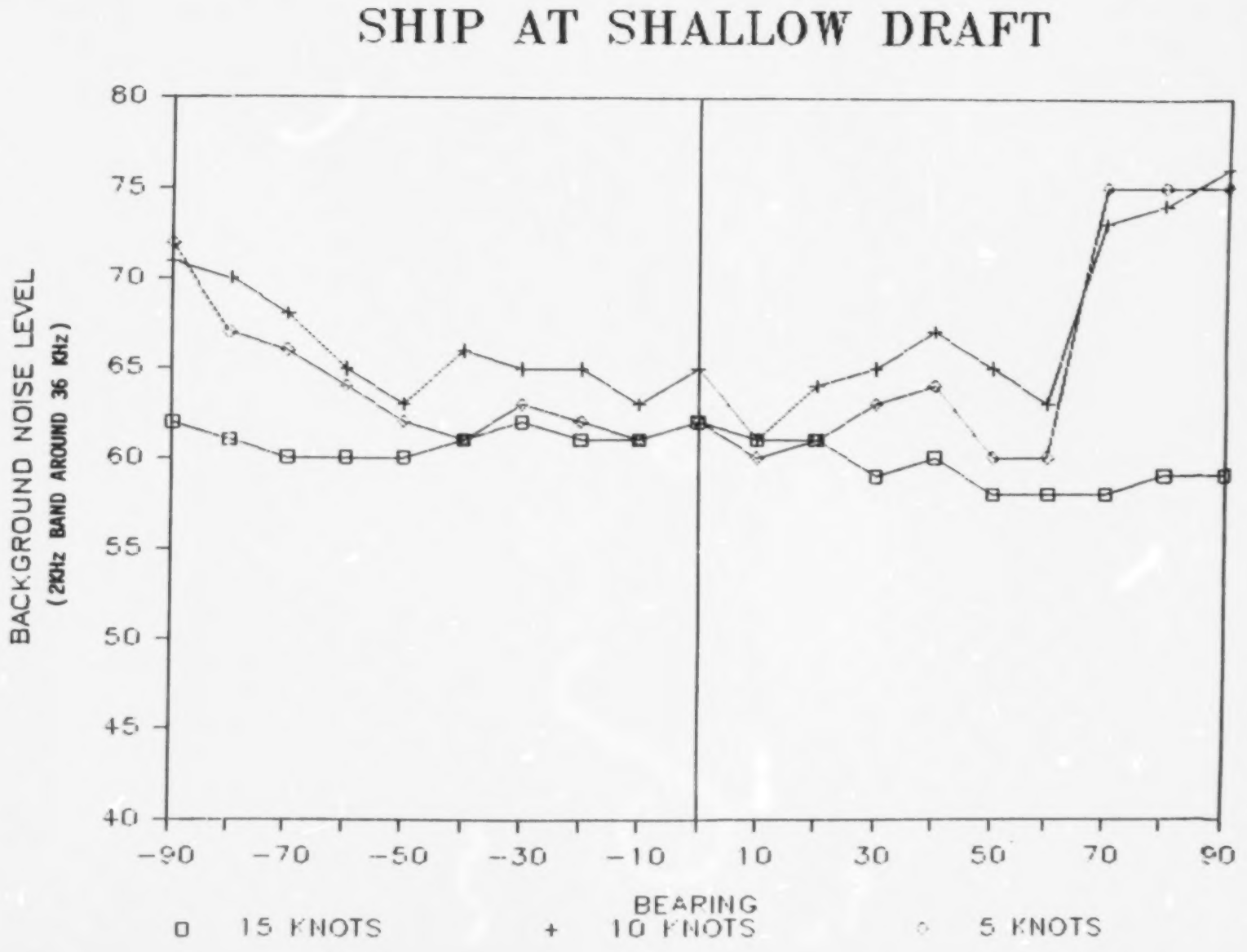
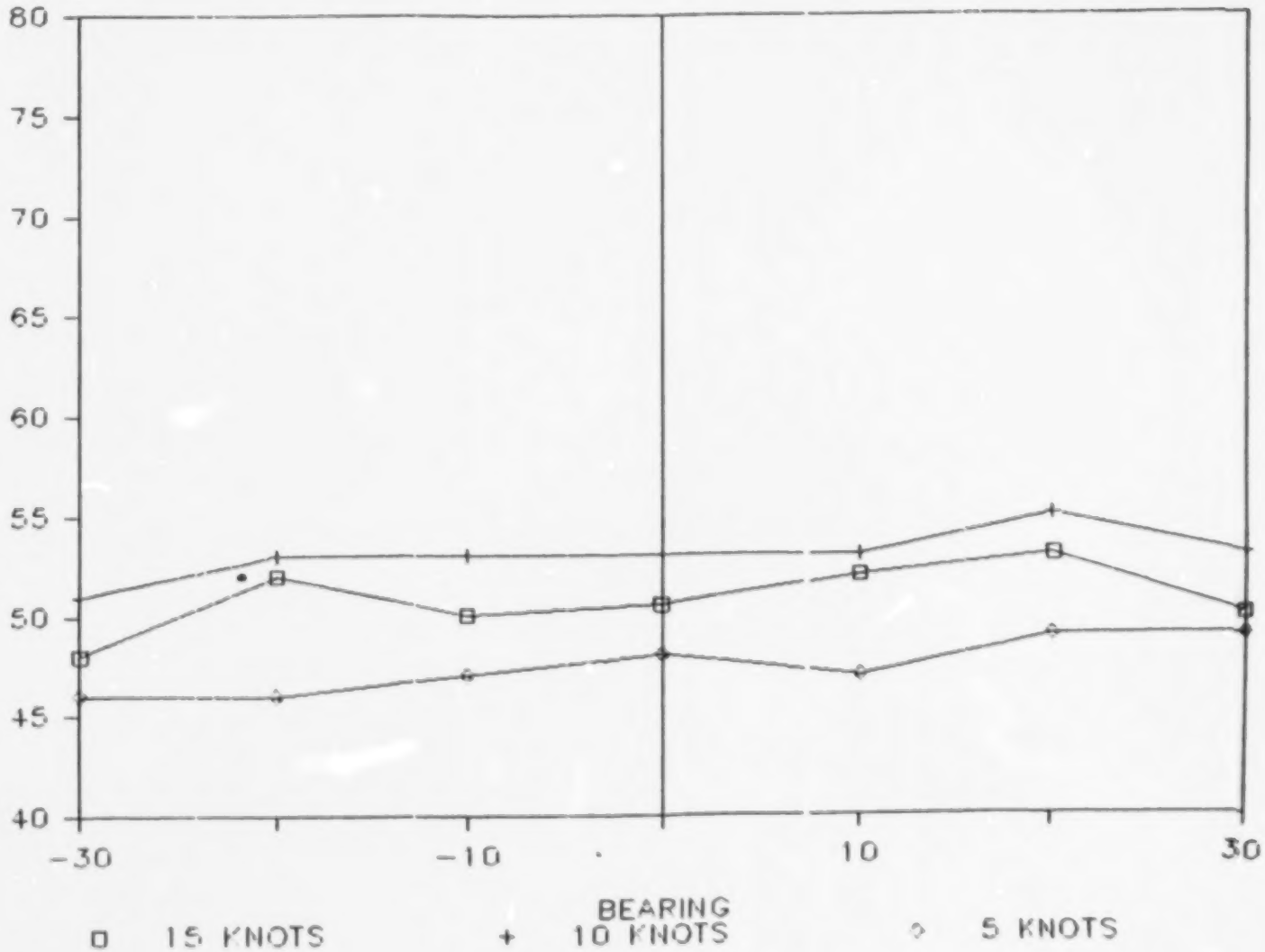


FIGURE 4.6: BACKGROUND NOISE LEVEL VS. BEARING, FOR DIFFERENT SPEEDS

SHIP AT ICEBREAKING DRAFT



BACKGROUND NOISE LEVEL VS BEARING
FOR DIFFERENT SPEEDS

To a first approximation the target strength of icebergs (assuming a smooth ice sphere) has been estimated as:

$$\text{Target Strength} = 6.7 \log M - 18 \text{ dB} \qquad (4.1)$$

where M is the Mass in tonnes.

This relation was derived as a result of a trying several simple but physically meaningful physical models (smooth sphere: eg 4.1, rough sphere, rough flat surface) with appropriate values for the reflectivity of ice. The relation (4.1), i.e. the target strength of an ideal smooth ice sphere appeared to fit the data best. Also, it is not without physical plausibility.

In deriving equation 4.1, the mean value of target strengths using a linear rather than a logarthmic form of the reflected energy has been used in the statistics. It has been assumed that the reflection loss at an ice/water interface is -10 dB.

This relationship has been plotted in Figure 4.2 along with the total target strength information. It is observed that the line is generally higher than the average target strength estimates. Possible reasons for this are related to the fact that the measurement procedure tended to underestimate the target strengths. Specifically:

1. Downward refracting propagation anomalies will reduce target strength at long range particularly for small targets.

2. Partial insonification of large targets at close ranges.

3. Saturation of large echoes within the receiving system.

Although not investigated mathematically in this project, echo correlation measurements may be an important addition in a more rigorous model. For a well defined target shape, good correlation between successive echoes should be observed. Conversely, poor correlation will result from a less well defined target.

4.6 AN ASSESSMENT OF ICEBERG DETECTABILITY USING THE CDS-40A SONAR

4.6.1 GENERAL COMMENTS

The C-Tech CDS-40A fish finding sonar that was specified for these trials generally proved to a worthy instrument for the detection trials. Its selection was based on its availability and cost as well as its overall technical specifications and display facilities. However, several sonar related limitations deserve mention as well.

Beamwidth — The vertical and horizontal beam patterns for the CDS-40A sonar were originally designed to satisfy commercial fishing operations involving the illumination of multiple, very small targets. The optimum beam pattern for this situation would exhibit a fairly wide beamwidth in both the horizontal and vertical planes. However, it is felt that a narrower beam pattern would offer better results for iceberg detection particularly those involving small targets.

Front - Back Ratio — This parameter describes the sensitivity of a sonar transducer to echoes or sound sources in a direction other than the main beam direction. With the CDS-40A transducer the front-back ratio is felt to be insufficient for clear displays. The problem is particularly noticeable in shallow depths where reverberation from the seafloor is high.

Sonar Display — To minimise the effect of the limited front-back ratio the display is designed with a limited dynamic range. This results in the loss of detectability of small targets when larger targets are present, in particular when one is constrained to avoid saturation.

Automatic Gain Control (AGC)

Although an AGC facility is provided, the need to make calibrated measurements prevented its use. The display limitations mentioned would not have been as serious had the AGC facility been used. The possibility may exist for the "audio" calibrated output to be independent of the AGC action.

4.6.2 SHADING EFFECT OF THE SHIP'S HULL

The positioning of the CDS-40A transducer close to the hull of the ship resulted in shading of the vertical beam. The net effect was to reduce the capability of the system to detect small, shallow draft icebergs close to the ship. For operational reasons it was not possible to quantify this effect. It is possible that this effect also contributed to a loss in performance at long range.

4.6.3 FACTORS AFFECTING THE DETECTABILITY OF ICEBERGS

The following factors were observed to affect the detectability of icebergs during the trials.

Target Size

In general large icebergs were detectable at longer ranges. This is because:

1. The target strength is a function of size.

2. Large targets have deeper keels.

Item 2 may apply only in summer when propagation conditions will tend to refract sound downwards. This suggestion has not been confirmed.

Water Depth

It was observed that in shallow water approximately 100 metres in depth, sound reverberation was more intense than that experienced in deeper waters. This phenomenon proved to be the limiting factor in range performance of the sonar.

Propagation Conditions	The downward refracting ray paths present in summer may limit the effective detection range of small icebergs. This effect is generally not present in winter or under-ice propagation conditions.
Target Geometry	No marked effect on detectability due to ice condition (fresh or weathered) was discoverd.
Target Aspect	Aspect has a marked effect on detectability. Reflections from rounded surfaces was noticeably less than from relatively flat surfaces.
Ship Speed	No significant effects were observed. Noise in the direction of the ship's wake could mask small targets.
Ice Cover	No data available.
Sonar Frequency	Single frequency system - no data available.
Sonar Controls	Detectability could be affected by incorrect or non-optimised control settings. AGC is a very desirable feature.

To summarize: it is felt that the sonar-independent main factor limiting the detection range in the conditions of the field trials was the downward refracting propagation. The major sonar-related factor is related to the beam characteristics of the sonar, and specifically in the beamwidth being too large (both vertical and horizontal) and the beam sidelobe characteristics being less than optimal.

5.0 CONCLUSIONS

The use of a commercial fish finding sonar in the detection of icebergs from a moving vessel has proved to be a feasible proposition. A preliminary analysis of echoes from 14 icebergs has indicated that echo amplitude is a function of iceberg mass. Large variations in echo shape and amplitude from specific icebergs confirm that the underwater shape can be very irregular, indicating that the reflecting properties may be better described in statistical terms. It has also been shown that, providing system calibration information is available, echo amplitude can be expressed in the more usual form as a Target Strength measurement.

The choice of the C-Tech CDS-40A sonar for this initial program proved to be wise. The panoramic display coupled with the ability for operator selection of a particular echo for observation enabled a library of echoes from each iceberg to be digitally recorded and subsequently analysed. In view of the time constraints this feature contributed to the success of the trials.

However, during the course of the investigations, several limitations of the sonar system in this development role became apparent. The resolution of the CDS-40A was limited by the relatively wide effective beam patterns in both the horizontal and vertical directions. This affected the detectability of small targets. In addition, limited side lobe suppression allowed the generation of side lobe echoes from strong targets. Finally, as the system operated at a single frequency, performance characteristics at other frequencies could not be evaluated.

The nature of the trials meant that certain compromises had to be made which probably degraded system performance. Signal processing techniques normally used for improvement of displays, namely automatic gain control for increasing the dynamic range, and threshold controls for noise reduction, could not be used in the trials due to the requirement to maintain overall calibration. Also deployment of the sonar head in the MV Arctic may have exceeded the design capabilities of the hoist mechanism.

For future trials with this sonar it is recommended that these areas be addressed.

From a sonar perspective, the following conclusions can be made:

1. Within the working range of the sonar, larger targets are generally detectable at larger ranges.

2. Sonar performance appears to be reverberation limited rather than by ship generated noise.

3. Side lobe leakage from strong off-axis targets was encountered.

4. Shallow water and rough sea conditions appeared to degrade range capability.

5. Seasonal changes in propagation characteristics can be expected to affect sonar performance.

The project was successful in producing an empirical relationship between the Target Strength of icebergs and physical size. The main conclusions from these investigations were:

1. Icebergs were observed to have an averaged Target Strength similar to that calculated for smooth ice spheres of equal mass.

2. To a first approximation

   Target Strength = 6.7 Log M - 18 db//1 m^2

   Where M = mass in tonnes.

3. The standard deviation of the Target Strength estimates for each iceberg was approximately equal to its mean value. This suggests that Target Strength of an iceberg may be modelled as an exponentially distributed random variable.

4. The duration of individual echoes from icebergs were observed in the range 20 ms to 60 ms probably due to beam pattern characteristics.

5. The frequency dependence of the Target Strength remains unknown.

6.0 RECOMMENDATIONS

This initial program has provided useful information concerning the detectability of icebergs using available sonar technology. However, before a final design specification for a hazard detecting sonar can be tabled, it is felt that further investigation is necessary. We feel that a two part program would be the most realistic approach in satisfying the requirements.

Further field programs are necessary in order to support and extend present knowledge regarding fundamental properties of acoustic propagation in arctic waters. Important here are investigations into the frequency dependence of target strength and in the signal to noise aspects of various transducer configurations and installations. Propagation characteristics under ice also demands attention. From a theoretical point of view some research into the statistical nature of sonar echoes and their relationship with radar echoes from the same target is thought to be important.

Of more immediate concern to the design of a suitable sonar for ice hazard detection is the more mechanical problems associated with the deployment of a transducer assembly within the bow area of the vessel. In this respect the positioning and "look direction" of a sonar transducer would have to be identified and the beam pattern and scanning rates defined. Further investigation into ship and ice generated noise is also desireable as noise parameters are necessary in the design of an optimal detector.

To be more specific, Table 6.1 outlines a possible sequence of major tasks that lead to the realization, installation and testing of a functional prototype of an ice detecting sonar. Some of the obvious intermediate steps have not been mentioned. Also the tasks for 1985 are more detailed than those for 1986 and 1987. Brief explanations to some of the points in the table are given below.

Table 6.1 is presented mainly as a basis for discussion, not as a fixed schedule. The main intent is to put activities proposed for 1986 in the perspective of more advanced development work.

Table 6.1 Sequence of Tasks Leading to Prototype Ice Detecting Sonar

TIME	MAJOR TASKS	SUB-TASKS	REMARKS
1. 1985	1.1 Definition, procurement and installation of sonar for 1.2		Probably an add-on to sonar used during 1984 field work
	1.2 Additional field measurements necessary for 1.4	1.2.1 Frequency dependence of target strength	During field season 1985
		1.2.2 Frequency dependence of back-ground noise, with and with-out ice cover	
		1.2.3 Reverberation with ice cover	
		1.2.4 Detection with ice cover	
		1.2.5 Correlation with radar	
	1.3 Analysis of field measurements		
	1.4 Top-level sonar design	1.4.1 Functional system design	
		1.4.2 Expected performance	

Table 6.1 Sequence of Tasks Leading to Prototype Ice Detecting Sonar (Cont'd)

TIME	MAJOR TASKS	SUB-TASKS	REMARKS
	1.5 Transducer design, procurement and test	1.5.1 Design 1.5.2 Procurement 1.5.3 Tests	One the basis of 1.3, 1.4 (i) Mechanical & accoustical self-standing (ii) Probably several iterations
2. 1986	2.1 Installation of transducer		
	2.2 Evaluation		During part of field season
	2.3 Design, procurement, test of prototype (other than transducer)		
	2.4 Installation o/b m.v. Arctic and static tests		
	2.5 Redesign of transducer		If necessary as result of 2.2
3. 1987	3.1 Installation of full system o/b mv Arctic		
	3.2 Tests		
	3.3 Design improvements		

Notes on Table 2

1.2 **DEFINITION ... OF SONAR**

The C-Tech CDS-40A sonar used for the 1984 work is operating on 36 KHz only. Some way needs to be found in order to procure and install a sonar operating on at least three frequencies, in order to ascertain any frequency dependent mechanism in the echo-formation by the iceberg. To this effect, it is important that the System be able to perform simulataneous or near simultaneous measurement or at least three frequencies.

1.3 **ADDITIONAL FIELD WORK**

Here, in addition to the echo frequency dependence, several other key factors need to be measured as they are not readily available form literature.

1.4 **SONAR DESIGN**

Note that the expected performance is determined at this point, so that the contract authority be able to make a judgement on the proposed performance.

2 The idea is to evaluate a transducer mechanical concept during extensive ice breaking, while work is proceeding on more "conventional" aspects of the system, such as signal processing, displays, hardware etc.

3 The system designed and built in 1986 and installed in 1987 will be designed in such a way as to readily accommodate design improvements. This will be achieved by doing all but the front-end signal processing, display and monitoring operation as much as possible in software.

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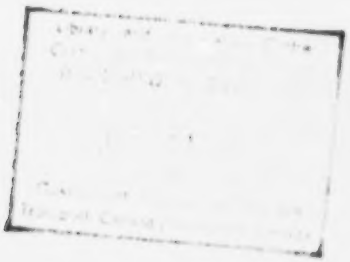

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Appendices
Proof of Concept Tests:
Data Acquisition and Analysis
for Close Range Hazard Detection

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15. Supplementary Notes Canarctic Shipping Company Limited 350 Sparks Street, Ottawa, Ontario K1R 7S8	16. TDC Project Officer M. Audette

17. Abstract

An evaluation of a commercial fish-finding sonar in an iceberg detecting role was undertaken during July and August, 1984, in the Davis Strait/Baffin Island region of the Canadian Arctic. A C-Tech CDS-40A sonar with an operating frequency of 36 kHz was mounted within the hull of the icebreaking freighter, the MV Arctic, and lowered as required. The sonar was used in a program of sea trials during a 72-hour period on a voyage of the MV Arctic between Antwerp, Belgium, and Nanisivik in Baffin Island.

The results suggest that a commercially available calibrated sonar system can be used to obtain quantitative and qualitative data which relate echo level (amplitude) to iceberg size. Measurements of echo level from ice pieces less than 100 tonnes and very large icebergs greater than 10 million tonnes indicate a range in values of target strength from -15 db to 35 db per square metre. Also, variations up to 40 db in target strength were obtained from multiple measurements on particular icebergs.

18. Key Words	19. Distribution Statement
Sonar, Ice Hazard Detection, MV Arctic, Marine Transportation, Target Strength, Echo Duration	Limited number of copies available from sponsoring agency.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
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17. Résumé

L'essai d'un sonar utilisé en pêcherie commerciale et transposé à la détection et à la reconnaissance des icebergs a été effectué de juillet à août 1984 dans le détroit de Davis et au large de l'île de Baffin. Un sonar C-Tech CDS-40A fonctionnant à la fréquence d'émission de 36 kHz a été monté à l'intérieur de la quille du cargo brise-glace Arctic et mis en oeuvre de la façon requise. Cet essai a eu lieu dans le cadre d'un programme d'essais en mer de 72 heures au cours de la liaison régulière de ce vraquier entre Anvers (Belgique) et Nanisivik (Ile de Baffin).

Les essais ont montré qu'un sonar de type commercial et convenablement étalonné fournit des données qui permettent de déterminer la taille des icebergs d'après l'intensité des échos reçus. Le mesurage des échos réfléchis par des icebergs d'une taille allant de 100 à 10 millions de tonnes a mis en évidence une gamme d'intensité d'échos variant entre -15 et 35 dB par mètre carré. De même, des variations d'un maximum de 40 dB dans l'intensité des échos ont été constatées dans le cas de certains icebergs à la suite de mesurages multiples.

18. Mots-clés	19. Diffusion
Sonar, détection des icebergs, Arctic, transport maritime, intensité d'échos, réverbération.	Nombre limité d'exemplaires disponible auprès de l'organisme parrian.

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APPENDIX I

CLASSIFICATION, MASS AND DRAFT DETERMINATION OF ICEBERGS

APPENDIX I

MASS AND DRAFT DETERMINATION OF ICEBERGS

For the purpose of classifying and estimating the mass of icebergs, we have used the following scheme, which, we understood is of common use amongst Canadian ice observers.

Type	Height (above sea level)	Length
growler	under 1.5 metres	under 5 metres
bergy bit	1.5 to 5 metres	5 to 15 metres
small berg	5 to 15 metres	15 to 60 metres
medium berg	15 to 50 metres	60 to 120 metres
large berg	50 to 100 metres	120 to 220 metres
very large berg	over 100 metres	over 220 metres

Bergs are also described according to shape and/or the average height to draft ratio, which can be as small as one to eight (seven-eights submerged). Following is the shape classification of icebergs used by the International Ice Patrol:

Type	Ratio	Description
blocky or tubular	1:5	rather flat on top with steep vertical sides
rounded or domed	1:4	large, smooth and rounded on on top
picturesque	1:3	varied and irregular
pinnacled or ridged	1:2	large central spire or pyramid with one or more spires surrounding
horned and winged or drydock	1:1	eroded such that a large U-shaped slot is formed near or at water level with twin columns or pinnacles

These ratios were derived from actual measurements of icebergs south of Newfoundland.

A reasonable estimate of the total iceberg mass in metric tons can be approximated by multiplying the above water portions of height times the width times the length, all in metres, and then multiplying this produce by a factor of 3.01. This factor partly accounts for the density difference between sea water and fresh water, and partly for the average shape and mass distribution. Considerable variation occurs in berg size according to geographical location. Some of the largest size bergs are in the 8.5 million ton size and are found near the source region. However, near latitude 48N, a one million ton berg is exceptional with most being less than half that figure.

APPENDIX II

THE SONAR EQUATION

APPENDIX II

THE SONAR EQUATION

For an active sonar system, the intensity of an echo received from a target is given in logarithmic form by the basic equation:

$$EL = SL - 2TL + TS \quad \ldots\ldots\ldots\ldots\ldots \quad A1$$

where EL is the echo level in db//1 μPa*
SL is the source level in db//1 μPa at 1 m
2TL is the two way transmission loss in db
and TS is the target strength in db//1 square metre

Equation A1 indicates that echo level will increase if the source level increases, and decrease if the transmission loss increases. The term Target Strength is the only acoustic parameter associated with the target that affects echo amplitude. Thus if both source level and transmission loss were constant, or known, then the echo level would reflect the target strength directly. Target strength can be defined as the ratio of the effective acoustic cross section area of a target and a standard area normally in square metres. This definition assumes that the whole target is illuminated by the sonar pulse.

In effect, the target strength for a uniform sphere is given by:

$$\text{Target Strength (TS)} = 10 \log \frac{I_R}{I_I} = 20 \log \frac{a}{2} \quad \ldots\ldots\ldots A2.2$$

where a = sphere radius
I_I = Incident Intensity
and I_R = Re-radiated Intensity at a distance of 1 m

---

*decibels relative to a pressure level of one micropascal (μPa)

Target Strength combines all effects that contribute to an echo into one parameter. Intuitively the larger a target, the greater the target strength will be. However, target strength does not take into account target shape or composition. Therefore if these are also variable, then the simple relationship involving only size will have to include shape, orientation and composition terms. The geometrical factors such as range are included in the transmission loss.

Use of Sonar Equation in the Estimation of Target Strength

Equation A2.1 can be rearranged to give the target strength in terms of the other parametres:

$$TS = EL + 2TL - SL \quad \ldots\ldots\ldots A2$$

If target strength is then to be derived from a measured echo level, the other parameters TL and SL in equation A2 must be known or able to be determined.

Source level is a basic specific parameter for most sonar systems and calibration information is usually available or can be measured. Under ideal conditions and with knowledge of the range and frequency, transmission loss can be computed. Thus, a direct measurement of the echo level and with knowledge of the sonar system receiving gains, a value of target strength can be obtained.

However, a fundamental aspect of all sonar work is the presence of ambient or other noise within the bandwidth of the receiving systems. It is usual to employ a threshold concept whereby a signal is deemed detectable, and therefore, measurable if the signal exceeds the noise by a certain factor. Noise as received by the receiving system must be within the bandwidth of the receiver. However, transducer directivity does reduce its effect. If we define the transducer by directivity index (DI) as a function of the effective beam pattern and the inband noise then a more realistic sonar equation or detection can be given by the inequality:

$$EL \geq SL - TL + TX + DI \text{ ..... } A3$$

In rearranging equation A3 to present target strength

$$TS \geq EL + TL - SL - DI \text{ db .....} A4$$

Since the measurement of echo level would be made by an electrical signal, the final formula for target strength would include additional parameters. Thus:

$$\text{Target Strength } TS = 20 \log V - S - G + TL - SL - DI \text{ db .....} A5$$

where echo level EL has been replaced by

$$EL = 20 \log V - S - G$$

where V is the measured voltage at the output of the receiving amplifier.

S is the receiving transducer sensitivity in db relative to 1 V / μPa

and G is the gain of the receiving amplifier in db

Thus, in summary:

$$TS = \underbrace{20 \log V}_{\text{Measured Parameter}} + \underbrace{2TL}_{\text{Transmission Effect}} - \underbrace{(SL + DI + S + G)}_{\text{System Parameter}} \text{ db .....} A6$$

Assuming the system parameters are constant (and known) during the course of the data acquisition program, then a measurement of a voltage and the estimation of a two way transmission loss will allow target strength to be obtained.

Estimates of Transmission Loss

The transmission loss for sea water can either be calculated or extracted from a graph.

In terms of pressure level, the one way transmission loss

$$TL = 20 \log R + 2\alpha R \text{ db}$$

assuming spherical spreading and R is range in metres. Thus, the two way transmission loss

$$2TL = 40 \log R + 2\alpha R \text{ db} \quad \ldots\ldots\ldots A7$$

where R is the range (metres) and α is the absorption coefficient (db/m) at the particular frequency.

At 36 KHz $\alpha = 0.01$ db/m

Therefore, $2TL = 40 \log R + 0.02 R$ db A8

APPENDIX III

CALIBRATION SPECIFICATIONS OF THE CDS-40A

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

37

Robert Van den Trook

C TECH LIMITED

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525 BOUNDARY ROAD
CORNWALL ONTARIO K6H 6N7

CALIBRATION DATA
CANARCTIC CDS-40A

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CHECKED	RVdB	09-07-84
APPROVED	[illegible]	9 July 84

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SHEET 1 OF 55

C-T557

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1. SCOPE

This report documents system performance and calibration data on a specific C-Tech Ltd. CDS-40A sonar system to allow transmitting source level and audio receiving response predictions to be made for use with the special "Audio & Recorder Interface Unit", C-Tech Ltd. P/N 12918, S/N 001. The following units form part of the subject system:

UNIT	PART NO.	SERIAL NO.
Control Indicator	12682 (modified)	37
Transmitter/Receiver	12452	29
Transducer/Dome Ass'y	12752-1/12353	24

2. OPERATIONAL CONSIDERATIONS

For preliminary instruction, please consult the "CDS-40A Operator's Manual". The following additional requirements should also be adhered to:

2.1 To operate the system in the calibrated mode, the AGC control must be turned to minimum (below 10% setting). This will place all gain parameters directly under operator control; note, however, that careful adjustment is necessary.

2.2 The audio mode must be selected from the screen menu using the cursor joystick and select pushbutton; the system will then operate in both video and audio modes alternately.

2.3 Position the target in the outer half of the sonar screen area in omni mode via the range scale selection if possible; this will maximize bearing readout resolution.

If the target must be positioned near the center of the screen, select the B scan (Attack) mode instead to preserve screen resolution.

2.4 Adjust the video presentation via the transmitter and/or receiver gain controls so that the target of interest is below red in the color scale (preferably orange to maximize dynamic range).

Red represents all signal levels greater than -1.2 dB re maximum output calibration reference, including clipping (saturation).

2.5 Position the cursor via the joystick such that its lower left hand corner is centered on the target of interest.

2.6 Record the bearing and tilt angle from the screen read-out, as well as the selected range scale.

2.7 Select the "Control Test Mode" and record the settings of the following controls:

Transmit Level

Transmit Pulse Length

STC Level

STC Slope

Gain

NOTE: The VCR interface may be used in conjunction with a VCR to record the information from steps 2.6 and 2.7.

2.8 Using the information noted in steps 2.6 and 2.7, and timing information derived from the companion tape recorder control system, the system source level and receiving response at target detection may be derived as set forth below.

3. SOURCE LEVEL PREDICTION

$Ls = k_a + k_b + k_c$

Ls = acoustic source level in dB/μPa

k_a = source level at selected transmit power level control setting from figure 2

k_b = relative output at selected tilt angle from figure 2 subtable

k_c = relative output at target bearing from appropriate azimuth transmit beam pattern

4. RECEIVING SENSITIVITY PREDICTION

$R_R = S_R + k_1 + k_2 + k_3 + k_4$

S_R = reference sensitivity, 82.6 dB/μPa

k_1 = normalized audio beam azimuth receiving response from Table 1

k_2 = normalized audio beam vertical response from Table 2

$k_3 = 20 \log (e_0/5.00\ V)$

where e_0 = peak to peak output voltage of recorder audio signal from Audio & Recorder Interface Unit, P/N 12198

k_4 = attenuation at time of target detection

for $|k_6| \geq |k_7|$, $k_4 = k_6$

for $|k_6| < |k_7|$, $k_4 = k_7$

$k_6 > k_7$

$k_6 \leq k_7$

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$$k_6 = 40 \log \left(\frac{T_{TVG}}{T_{STC}} + 10^{(.025\ k_5)} \right)$$ OK

$T_{TVG} = T_{RC} - T_{TX}$

T_{RC} = Time from reference clock start-up to target detection. Refer to system timing diagram, figure 1, and see note below.

T_{TX} = Transmit pulse length from figure 3

T_{STC} = STC slope time from Table 5

k_5 = initial attenuation value determined by STC level control setting from Table 3

k_7 = final attenuation determined by gain control setting from Table 4

NOTE: If the timing information from the tape recorder control system is not accessible, a less accurate approximation may be made from the sonar screen surface range readout according to the following formula:

$$T_{RC} = \frac{R_s}{750 \cdot \cos \theta}$$

T_{RC} = time from reference clock start-up to target detection in seconds

θ = tilt angle in degrees

R_S = target surface range readout in meters

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Figure 1. SYSTEM TIMING DIAGRAM.

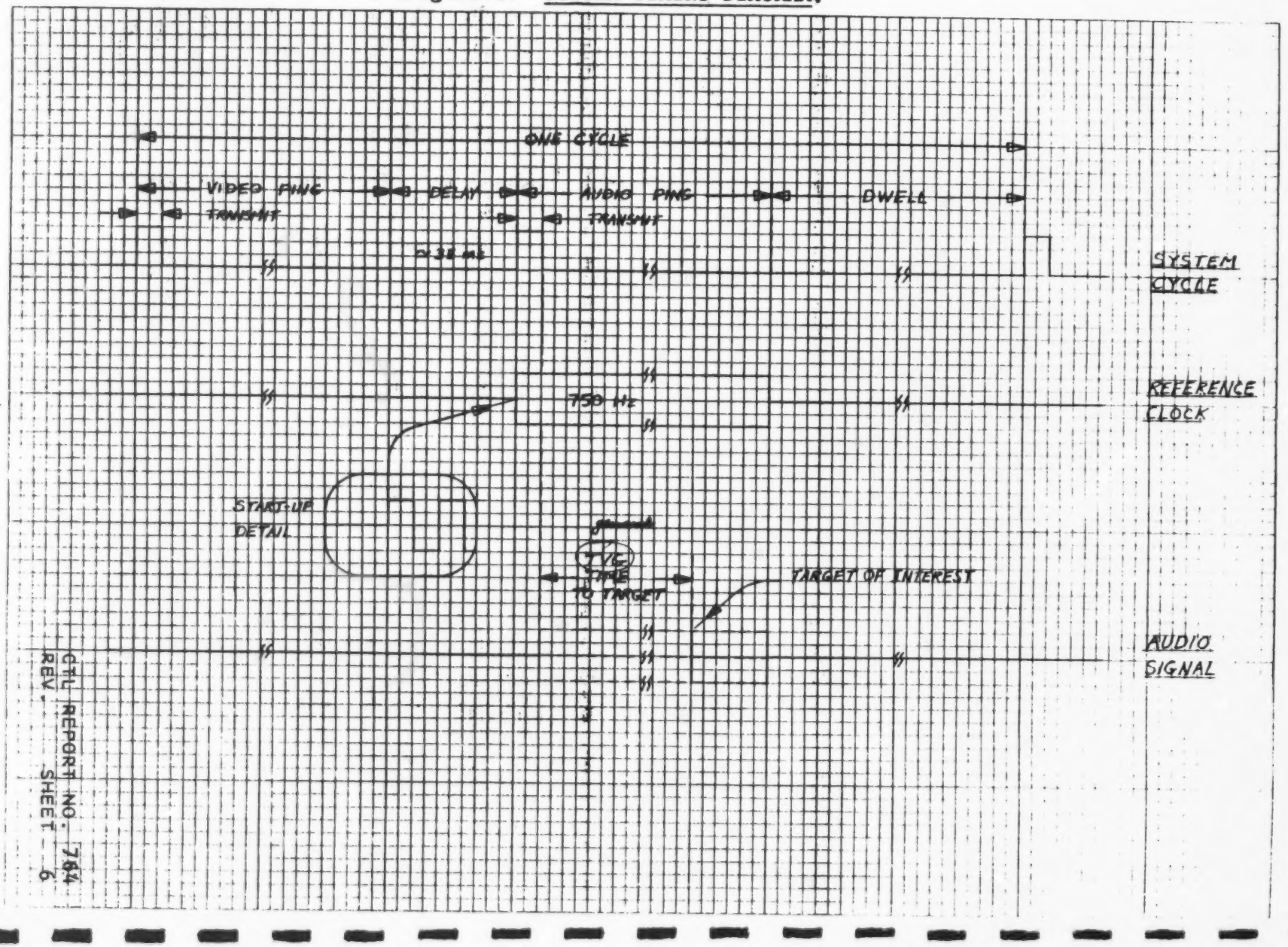

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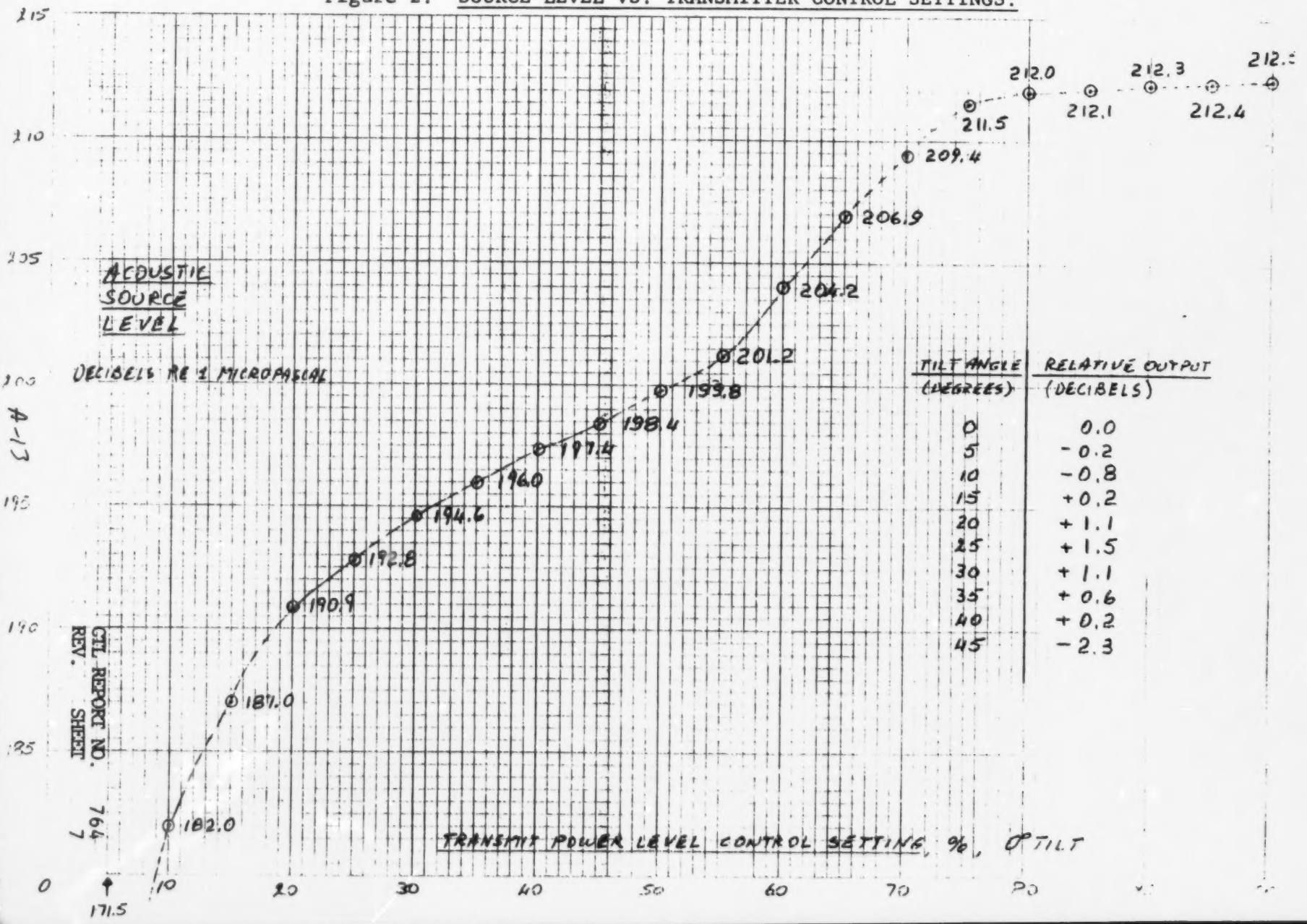
Figure 2. SOURCE LEVEL VS. TRANSMITTER CONTROL SETTINGS.



TILT ANGLE (DEGREES)	RELATIVE OUTPUT (DECIBELS)
0	0.0
5	- 0.2
10	- 0.8
15	+ 0.2
20	+ 1.1
25	+ 1.5
30	+ 1.1
35	+ 0.6
40	+ 0.2
45	- 2.3

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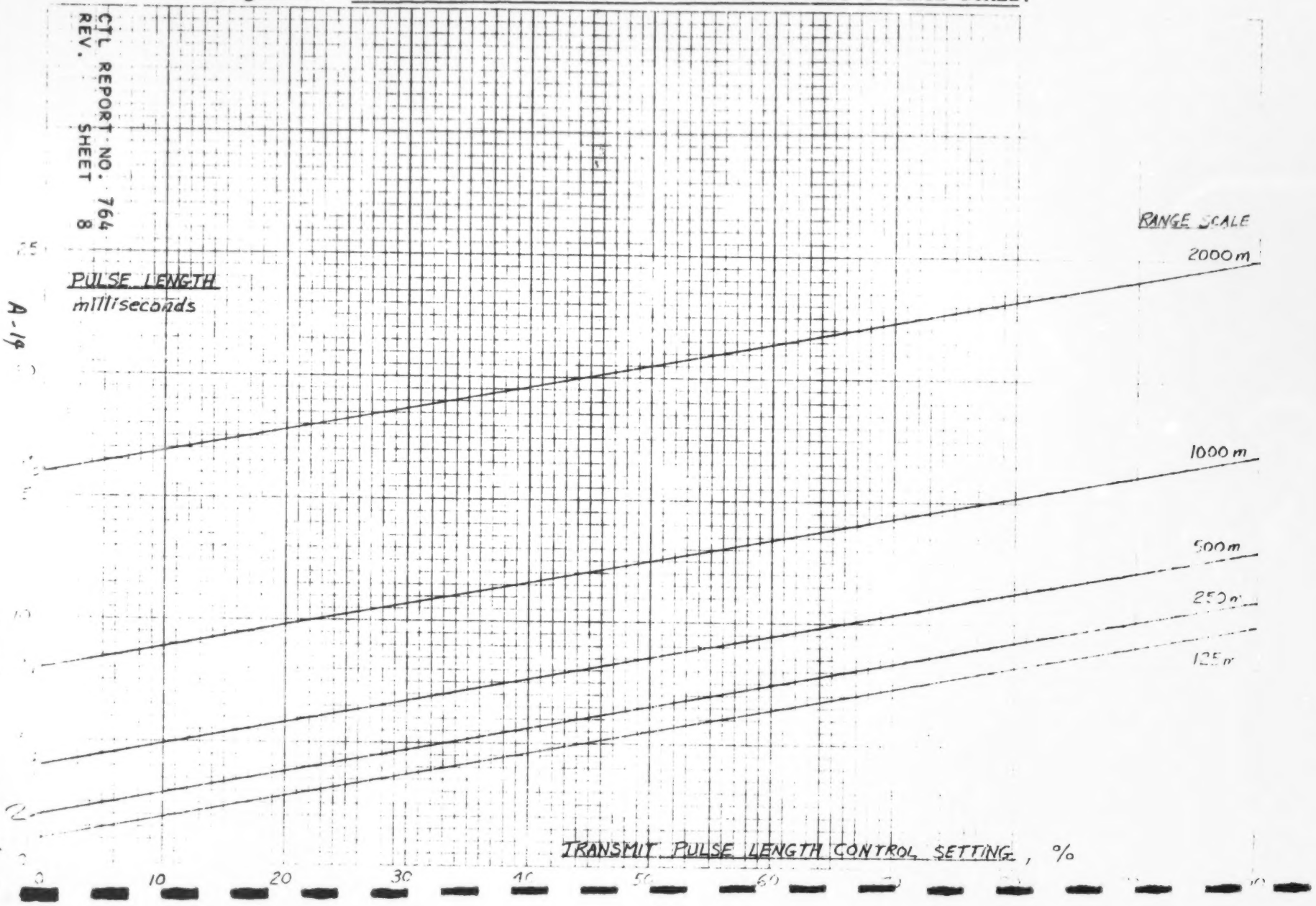
Figure 3. TRANSMIT PULSE LENGTH VS. CONTROL SETTING & RANGE SCALE.



AUDIO BEAM RECEIVING RESPONSE

REFERENCE SENSITIVITY: 82.6 dB re 1 micropascal at 0° bearing, 0° tilt, maximum gain, full scale audio signal output

TABLE 1. NORMALIZED AUDIO BEAM AZIMUTH RECEIVING RESPONSE

BEARING (DEGREES)	SENSITIVITY (DECIBELS)	BEARING (DEGREES)	SENSITIVITY (DECIBELS)	BEARING (DEGREES)	SENSITIVITY (DECIBELS)
0.0	0.0	67.5	-0.7	135.0	+0.3
2.25	-0.4	69.75	-0.5	137.25	-0.2
4.5	-0.5	72.0	-0.2	139.5	-0.2
6.75	-0.3	74.25	-1.0	141.75	0.0
9.0	+0.1	76.5	-0.3	144.0	+0.4
11.25	-0.3	78.75	-0.7	146.25	-0.1
13.5	-0.4	81.0	-0.3	148.5	-0.2
15.75	-0.1	83.25	-0.7	150.75	0.0
18.0	+0.2	85.5	-0.7	153.0	+0.3
20.25	-0.3	87.75	-0.5	155.25	0.0
22.5	-0.8	90.0	-0.1	157.5	-0.1
24.75	-0.3	92.25	-0.5	159.75	+0.2
27.0	+0.1	94.5	-0.7	162.0	+0.5
29.25	-0.3	96.75	-0.5	164.25	+0.1
31.5	-0.4	99.0	-0.1	166.5	-0.1
33.75	-0.1	101.25	-0.5	168.75	+0.1
36.0	+0.1	103.5	-0.5	171.0	+0.5
38.25	-0.3	105.75	-0.2	173.25	0.0
40.5	-0.5	108.0	+0.1	175.5	0.0
42.75	-0.4	110.25	-0.3	177.75	+0.2
45.0	0.0	112.5	-0.4	180.0	+0.6
47.25	-0.5	114.75	-0.2	182.25	-0.7
49.5	-0.6	117.0	+0.2	184.5	0.0
51.75	-0.4	119.25	-0.2	186.75	+0.1
54.0	0.0	121.5	-0.3	189.0	-0.5
56.25	-0.5	123.75	-0.1	191.25	0.0
58.5	-0.6	126.0	+0.3	193.5	-0.1
60.75	-0.5	128.25	-0.2	195.75	-0.7
63.0	-0.2	130.5	-0.3	198.0	+0.4
65.25	-0.6	132.75	-0.2	200.25	-0.1

TABLE 1. NORMALIZED AUDIO BEAM AZIMUTH RECEIVING RESPONSE. - Continued

BEARING (DEGREES)	SENSITIVITY (DECIBELS)	BEARING (DEGREES)	SENSITIVITY (DECIBELS)	BEARING (DEGREES)	SENSITIVITY (DECIBELS)
202.5	-0.2	256.5	-0.3	308.25	-0.2
204.75	-0.1	258.75	-0.1	310.5	-0.4
207.0	+1.3	261.0	+0.3	312.75	-0.2
209.25	-0.1	263.25	-0.2	315.0	+0.1
211.5	-0.2	265.5	-0.2	317.25	-0.3
213.75	0.0	267.75	0.0	319.5	-0.4
216.0	+0.3	270.0	+0.3	321.75	-0.2
218.25	-0.2	272.25	-0.2	324.0	+0.1
220.5	-0.3	274.5	-0.3	326.25	-0.4
222.75	-0.1	276.75	-0.2	328.5	-0.5
225.0	+0.2	279.0	+0.2	330.75	-0.4
227.25	-0.2	281.25	-0.2	333.0	-0.1
229.5	-0.3	283.5	-0.3	335.25	-0.5
231.75	0.0	285.75	-0.1	337.5	-0.6
234.0	+0.3	288.0	+0.3	339.75	-0.4
236.25	-0.2	290.25	-0.2	342.0	0.0
238.5	-0.3	292.5	-0.4	344.25	-0.5
240.75	-0.1	294.75	-0.2	346.5	-0.6
243.0	-0.2	297.0	+0.2	348.75	-0.5
245.25	-0.2	299.25	-0.3	351.0	-0.1
247.5	-0.3	301.5	-0.1	353.25	-0.6
249.75	0.0	303.75	-0.1	355.5	-0.7
252.0	+0.3	306.0	+0.3	357.75	-0.4
254.25	-0.2				

TABLE 2. NORMALIZED AUDIO BEAM VERTICAL RESPONSE.

TILT ANGLE (DEGREES)	SENSITIVITY (DECIBELS)	TILT ANGLE (DEGREES)	SENSITIVITY (DECIBELS)
0	0.0	25	-0.6
5	-0.6	30	-1.0
10	-0.2	35	-1.9
15	-0.3	40	-2.8
20	-0.4	45	-4.5

TABLE 3. INITIAL ATTENUATION VS. STC LEVEL CONTROL SETTING.

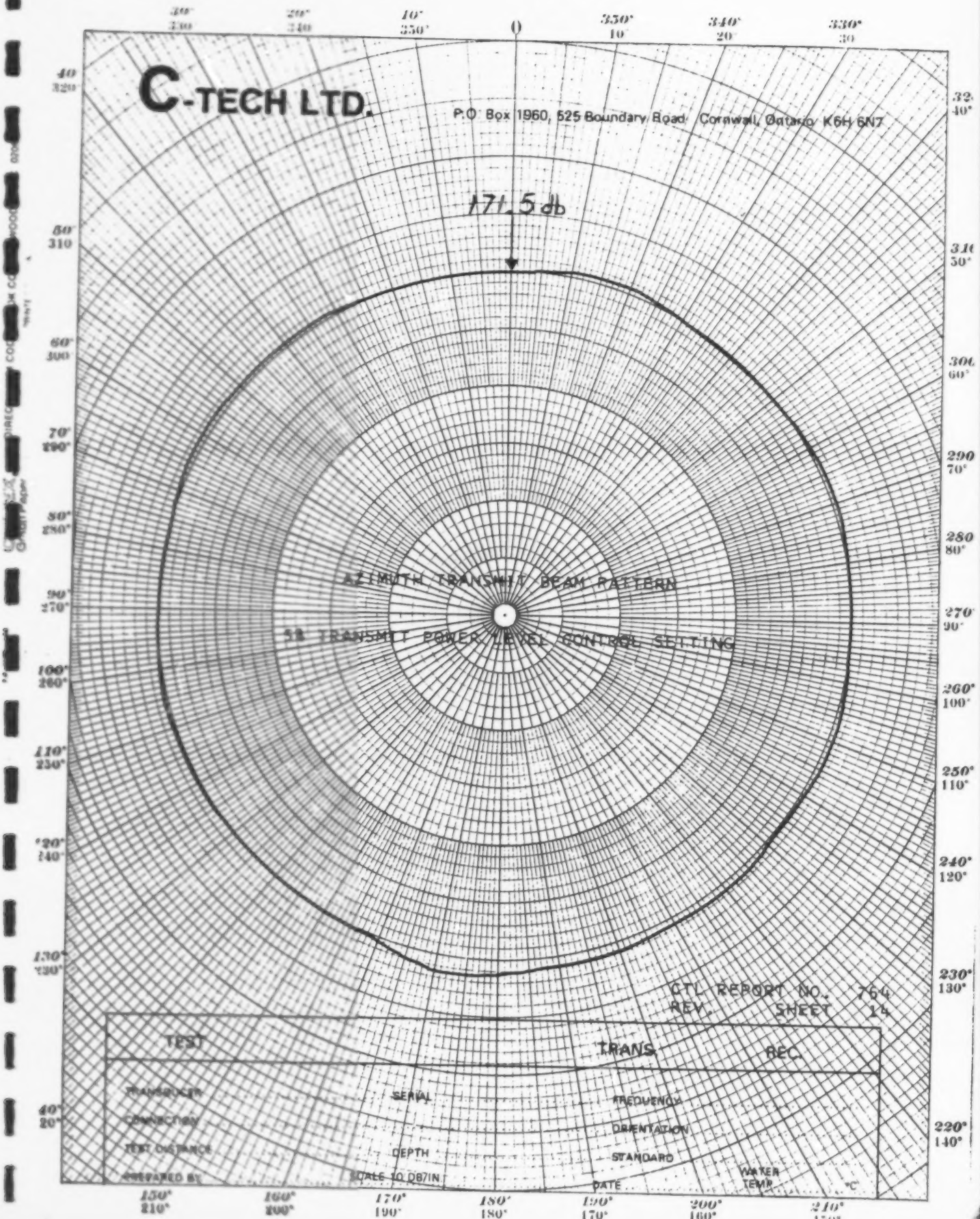
CONTROL SETTING	ATTENUATION (DECIBELS)	CONTROL SETTING	ATTENUATION (DECIBELS)	CONTROL SETTING	ATTENUATION (DECIBELS)
0	-35.3	34	-45.4	68	-55.5
1	-35.6	35	-45.8	69	-55.9
2	-35.6	36	-46.1	70	-56.3
3	-36.0	37	-46.5	71	-56.6
4	-36.4	38	-46.5	72	-57.0
5	-36.8	39	-46.9	73	-57.0
6	-37.1	40	-47.3	74	-57.4
7	-37.5	41	-47.6	75	-57.8
8	-37.5	42	-47.6	76	-58.1
9	-37.9	43	-48.0	77	-58.5
10	-38.3	44	-48.4	78	-58.5
11	-38.6	45	-48.8	79	-58.9
12	-38.6	46	-49.1	80	-59.3
13	-39.0	47	-49.1	81	-59.6
14	-39.4	48	-49.5	82	-60.0
15	-39.8	49	-49.9	83	-60.0
16	-40.1	50	-50.3	84	-60.4
17	-40.1	51	-50.6	85	-60.8
18	-40.5	52	-51.0	86	-61.1
19	-40.9	53	-51.0	87	-61.5
20	-41.3	54	-51.4	88	-61.5
21	-41.6	55	-51.8	89	-61.9
22	-42.0	56	-52.1	90	-62.3
23	-42.0	57	-52.5	91	-62.6
24	-42.4	58	-52.5	92	-63.0
25	-42.8	59	-52.9	93	-63.0
26	-43.1	60	-53.3	94	-63.4
27	-43.1	61	-53.6	95	-63.8
28	-43.5	62	-53.6	96	-64.1
29	-43.9	63	-54.0	97	-64.5
30	-44.3	64	-54.4	98	-64.5
31	-44.6	65	-54.8	99	-64.9
32	-44.6	66	-55.1	100	-65.3
33	-45.0	67	-55.5		

TABLE 4. FINAL ATTENUATION VS. GAIN CONTROL SETTING

CONTROL SETTING	ATTENUATION (DECIBELS)	CONTROL SETTING	ATTENUATION (DECIBELS)	CONTROL SETTING	ATTENUATION (DECIBELS)
0	-71.6	34	-47.3	68	-23.3
1	-70.5	35	-46.5	69	-22.1
2	-70.1	36	-45.8	70	-21.8
3	-69.4	37	-45.0	71	-21.0
4	-68.6	38	-44.6	72	-19.9
5	-67.9	39	-43.5	73	-19.5
6	-67.1	40	-43.1	74	-18.8
7	-66.4	41	-42.4	75	-18.0
8	-66.0	42	-41.6	76	-17.3
9	-64.9	43	-40.9	77	-16.5
10	-64.5	44	-40.1	78	-15.8
11	-63.8	45	-39.4	79	-15.4
12	-63.0	46	-38.6	80	-14.3
13	-62.3	47	-37.9	81	-13.9
14	-61.5	48	-37.1	82	-13.1
15	-60.8	49	-36.8	83	-12.4
16	-60.0	50	-35.6	84	-11.6
17	-59.3	51	-35.3	85	-10.9
18	-58.5	52	-34.5	86	-10.1
19	-58.1	53	-33.8	87	- 9.4
20	-57 0	54	-33.0	88	- 8.6
21	-56.6	55	-32.3	89	- 7.9
22	-55.9	56	-31.5	90	- 7.5
23	-55.1	57	-30.8	91	- 6.4
24	-54.4	58	-30.0	92	- 6.0
25	-53.6	59	-29.3	93	- 5.3
26	-52.9	60	-28.9	94	- 4.5
27	-52.5	61	-27.8	95	- 3.8
28	-51.4	62	-27.4	96	- 3.0
29	-50.6	63	-26.6	97	- 2.3
30	-50.3	64	-25.9	98	- 1.9
31	-49.1	65	-25.1	99	- 0.8
32	-48.8	66	-24.4	100	- 0.0
33	-48.0	67	-23.6		

TABLE 5. STC SLOPE TIME VS. STC SLOPE CONTROL SETTING

CONTROL SETTING	SLOPE TIME (MILLISECONDS)	CONTROL SETTING	SLOPE TIME (MILLISECONDS)	CONTROL SETTING	SLOPE TIME (MILLISECONDS)
0	267.8	34	618.4	68	2615
1	276.5	35	641.5	69	2833
2	281.1	36	660.3	70	2956
3	288.3	37	680.0	71	3238
4	293.3	38	701.2	72	3578
5	301.0	39	731.3	73	3777
6	305.1	40	747.2	74	3999
7	313.5	41	781.7	75	4250
8	319.4	42	800.1	76	4856
9	327.1	43	829.4	77	5230
10	333.5	44	871.7	78	5665
11	341.9	45	894.8	79	6181
12	347.1	46	931.6	80	6798
13	358.1	47	957.7	81	7554
14	367.7	48	999.9	82	8497
15	373.7	49	1030	83	9711
16	384.2	50	1079	84	11328
17	393.2	51	1115	85	13321
18	402.4	52	1172	86	
19	412.2	53	1214	87	
20	425.0	54	1283	88	
21	433.1	55	1333	89	
22	444.7	56	1388	90	
23	453.4	57	1416	91	
24	468.7	58	1478	92	
25	478.8	59	1619	93	
26	492.7	60	1700	94	
27	503.8	61	1789	95	
28	523.1	62	1889	96	
29	539.6	63	2000	97	
30	552.9	64	2060	98	
31	571.5	65	2266	99	
32	586.2	66	2345	100	
33	607.1	67	2518		


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario, K6H 6N7
171.5 db
AZIMUTH TRANSMIT BEAM PATTERN
5% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV.
SHEET 14
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP.
°C
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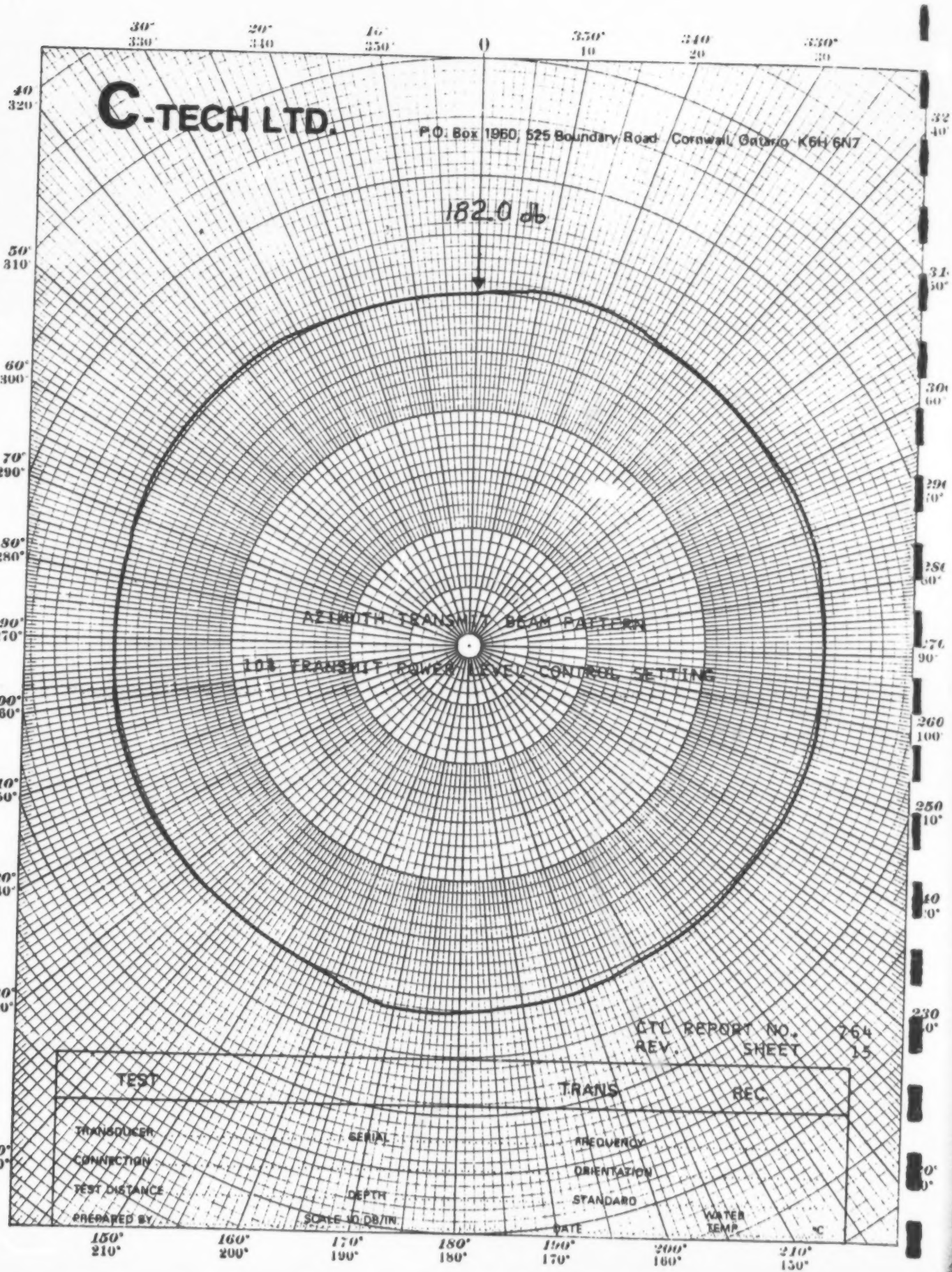
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
182.0 db
AZIMUTH TRANSMIT BEAM PATTERN
10% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 264
REV.
SHEET 15
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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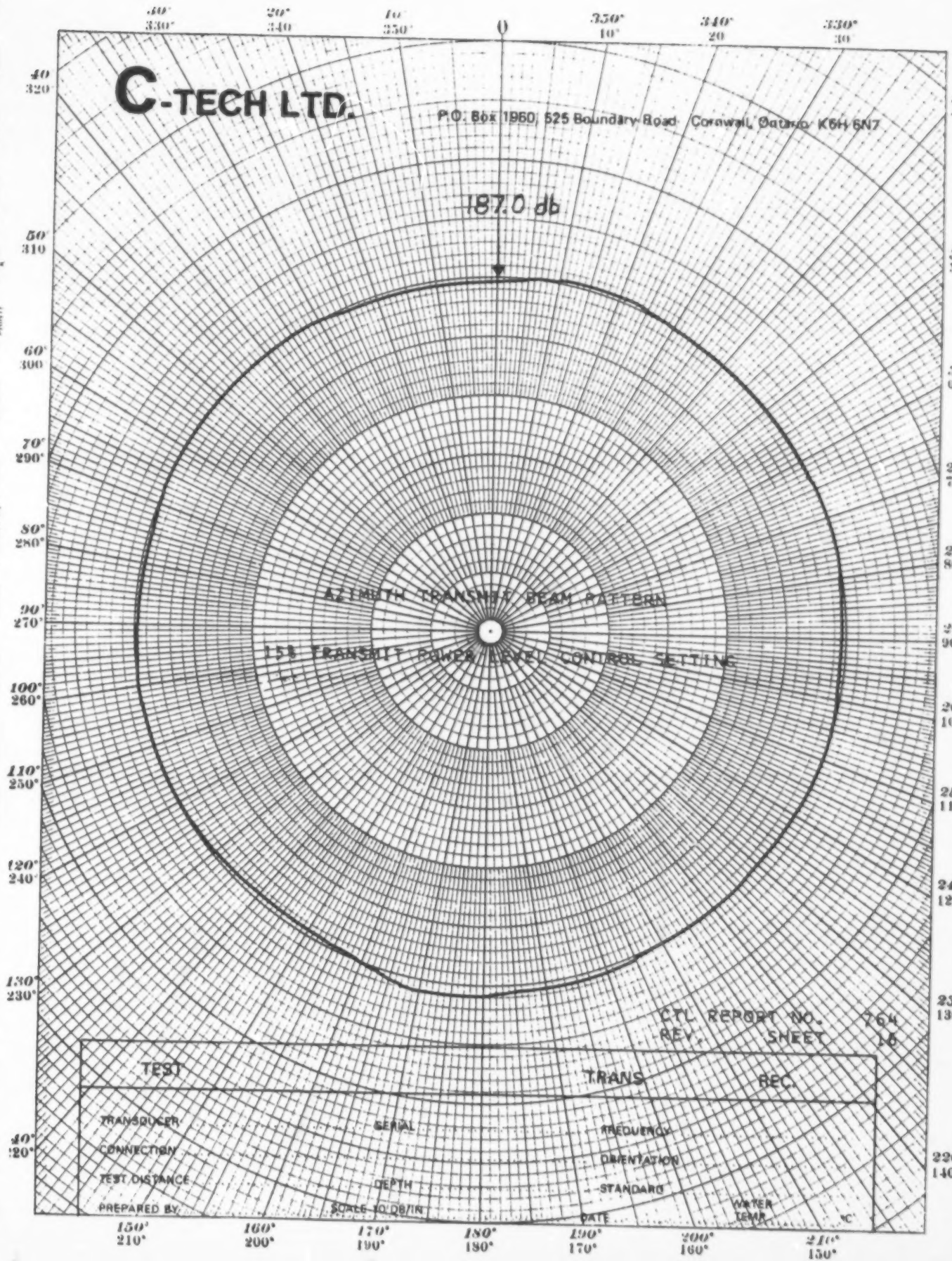
C-TECH LTD.
P.O. Box 1950, 525 Boundary Road Cornwall, Ontario K6H 6N7
187.0 db
AZIMUTH TRANSMIT BEAM PATTERN
15% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 16
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP.
°C
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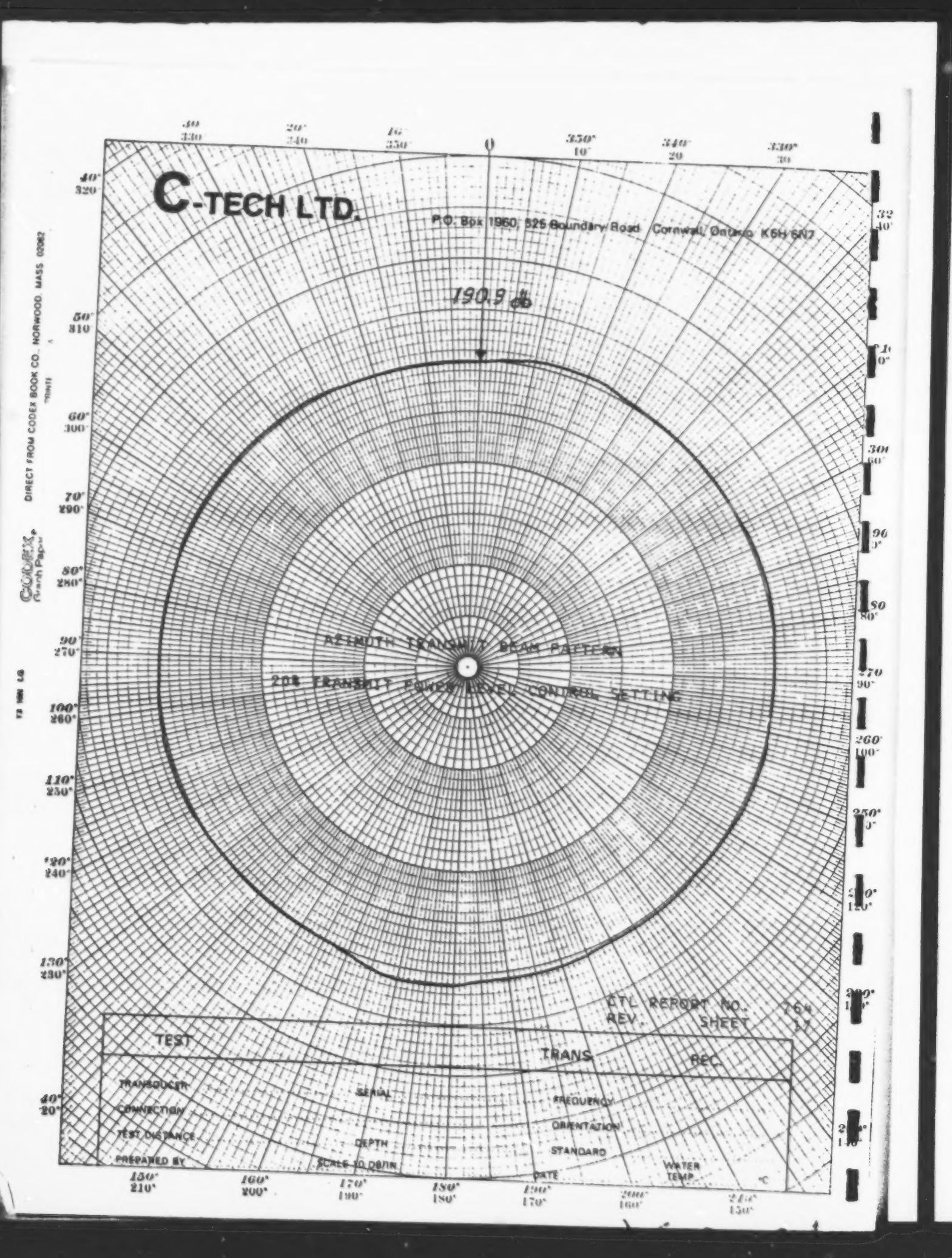
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
190.9 dB
AZIMUTH TRANSMIT BEAM PATTERN
20% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO.
REV.
SHEET
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
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PREPARED BY
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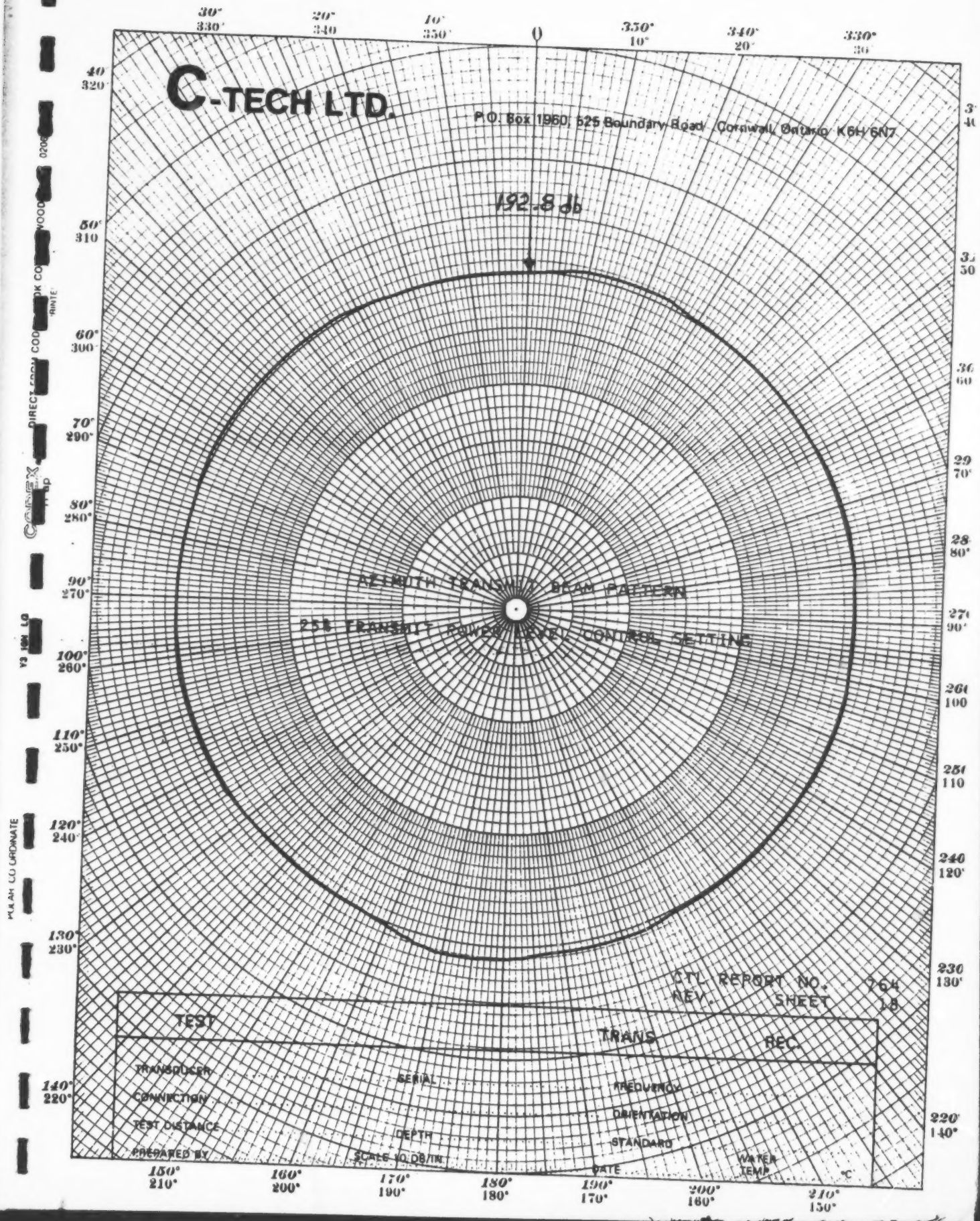
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
°C


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario K6H 6N7
192.8 db
AZIMUTH TRANSMIT BEAM PATTERN
25% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 18
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
°C
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10° 350°
20° 340°
30° 330°
40 320°
50° 310°
60° 300°
70° 290°
80° 280°
90° 270°
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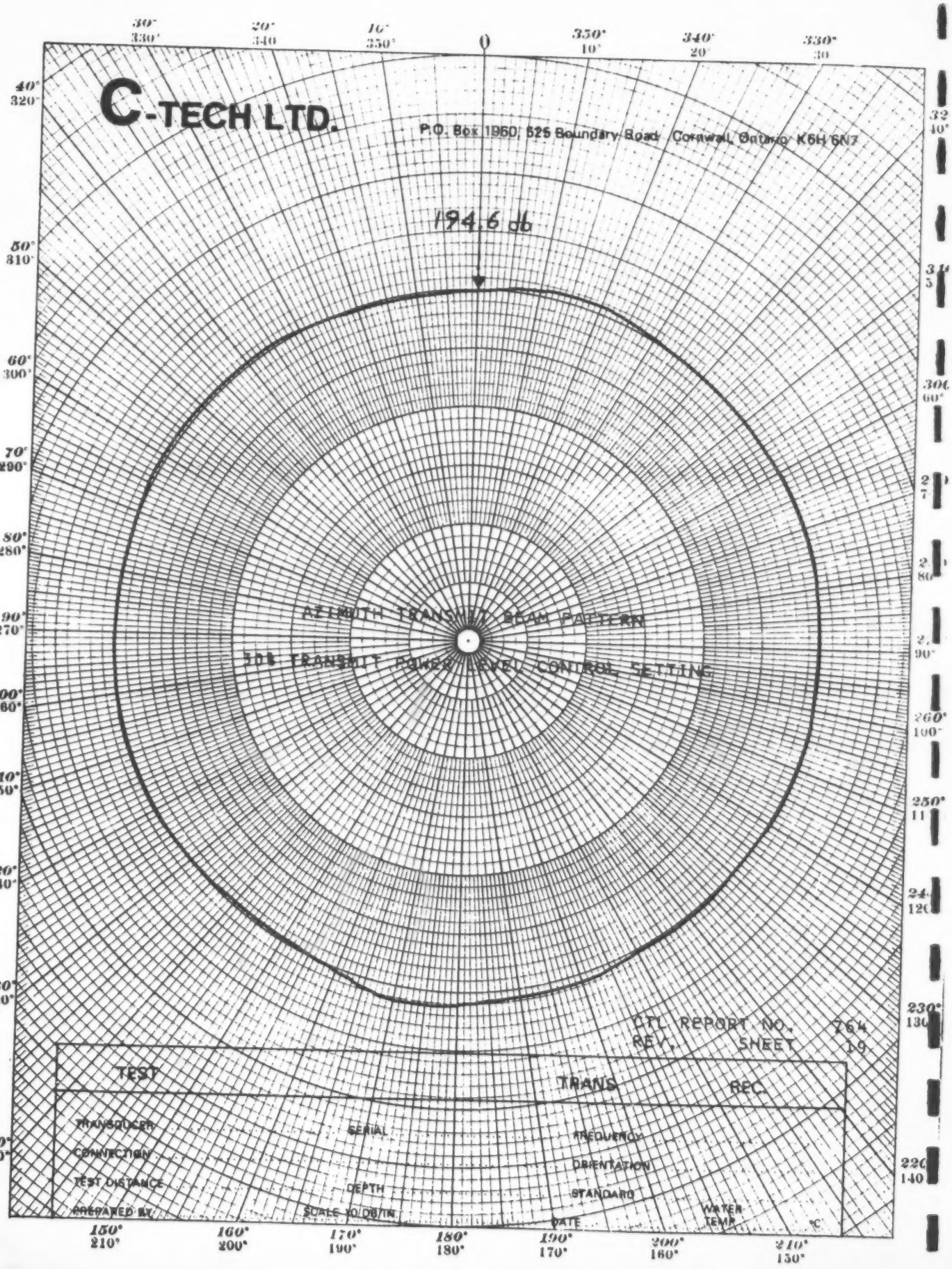
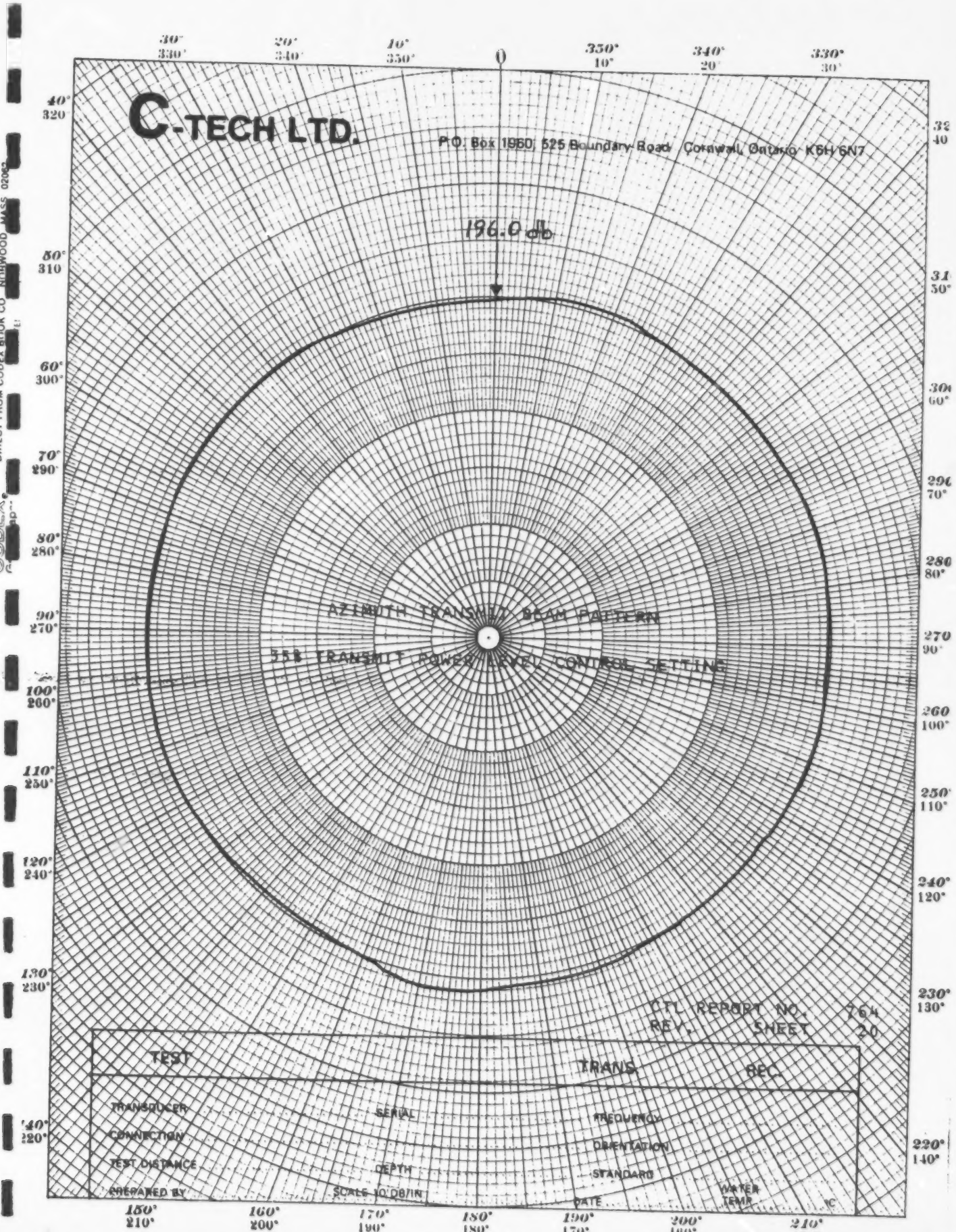

C-TECH LTD.
P.O. Box 1950, 525 Boundary Road, Cornwall, Ontario K6H 6N7
194.6 dB
AZIMUTH TRANSMIT BEAM PATTERN
50% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO.
REV.
SHEET
764
19
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
°C
DIRECT FROM CODEX BOOK CO., NORWOOD, MASS 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1950, 525 Boundary Road, Cornwall, Ontario K6H 6N7
196.0 db
AZIMUTH TRANSMIT BEAM PATTERN
35% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV.
SHEET 20
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
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20° 340°
10° 350°
350° 10°
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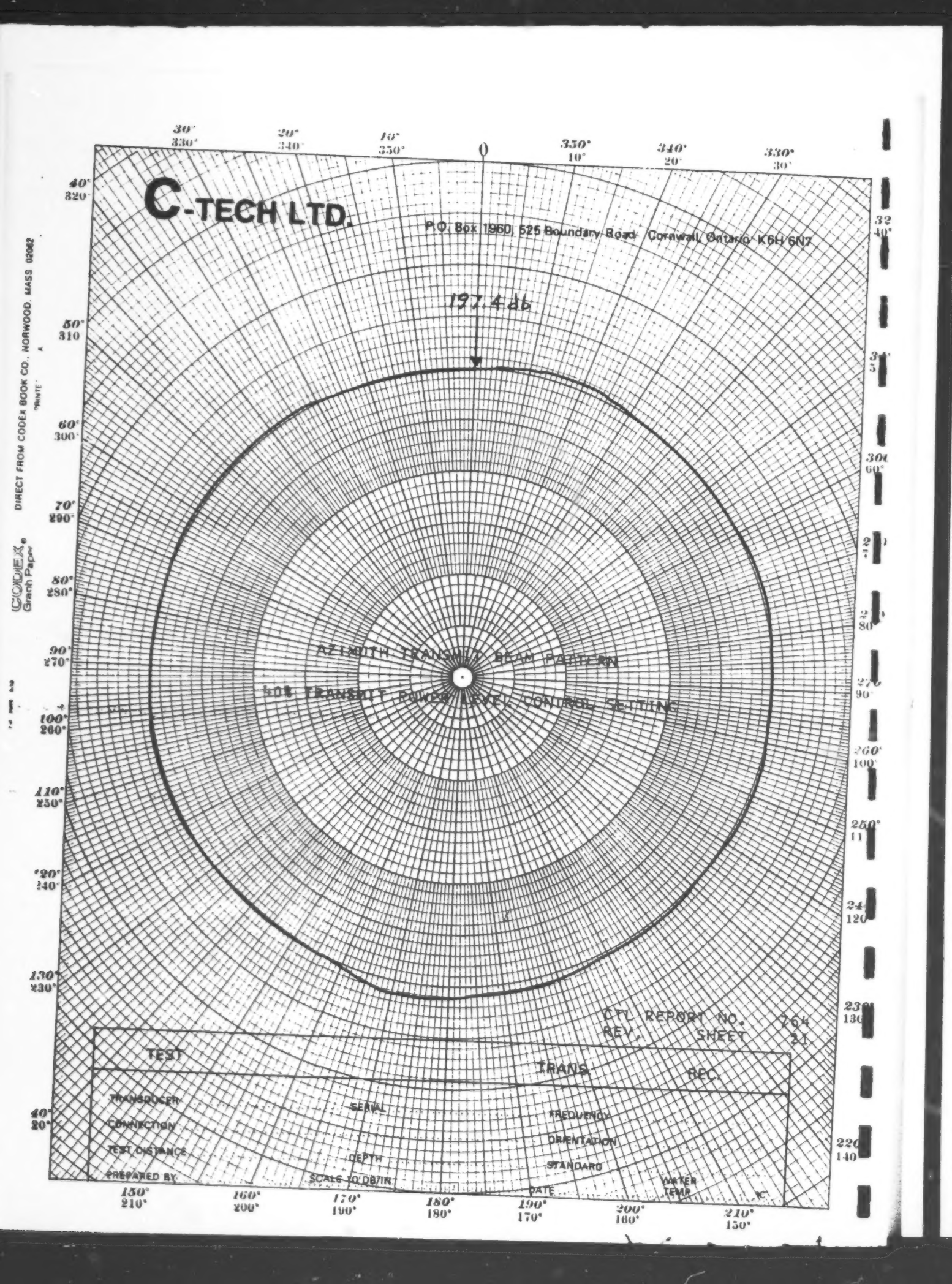
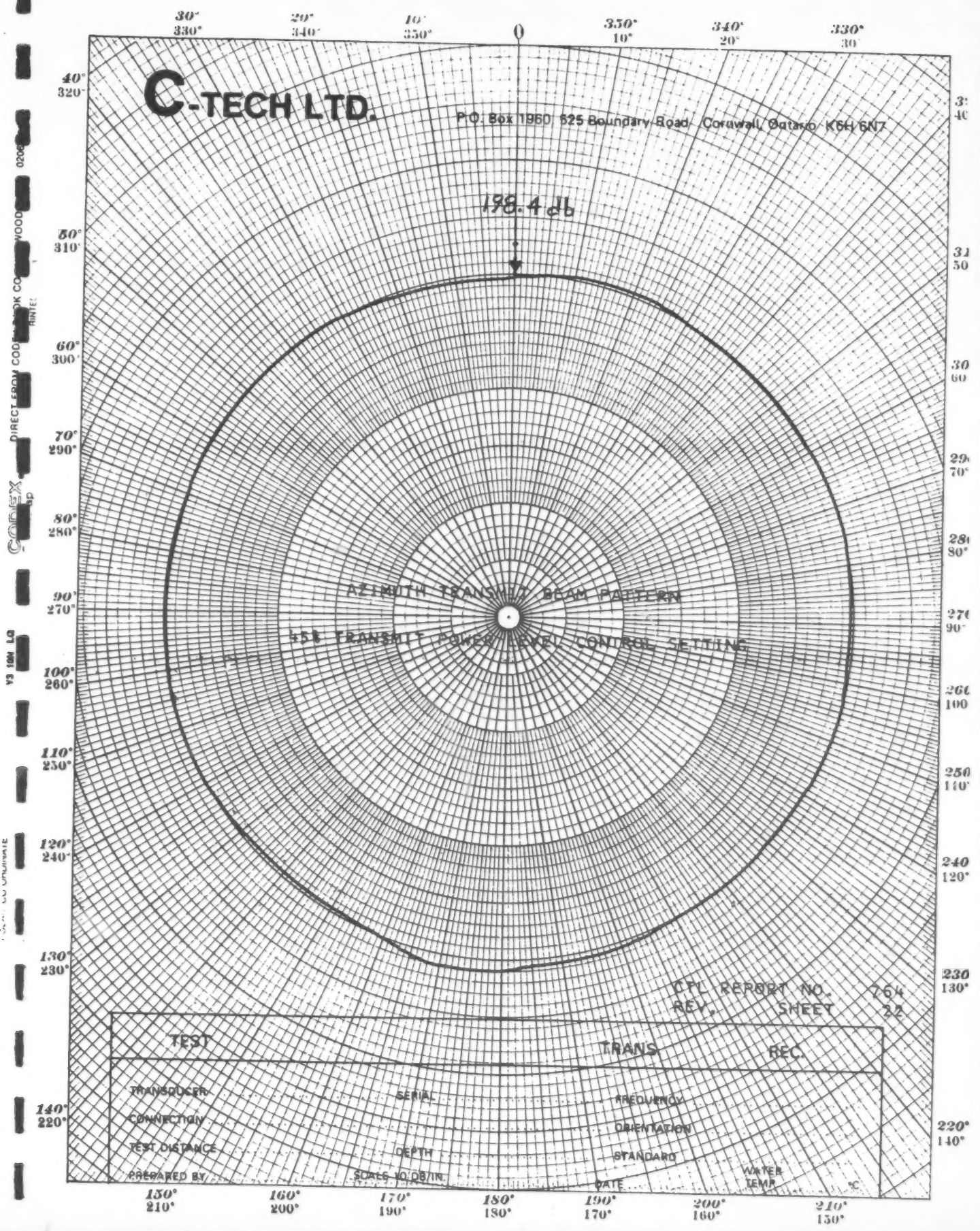
DIRECT FROM CODEX BOOK CO. NORWOOD, MASS. 02062


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario K6H 6N7
197.4 db
AZIMUTH TRANSMIT BEAM PATTERN
50% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 264
REV. SHEET 21
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN.
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
DIRECT FROM CODEX BOOK CO., NORWOOD, MASS 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario, K6H 6N7
198.4 db
AZIMUTH TRANSMIT BEAM PATTERN
45% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 22
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN.
DATE
WATER TEMP
°C
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10°
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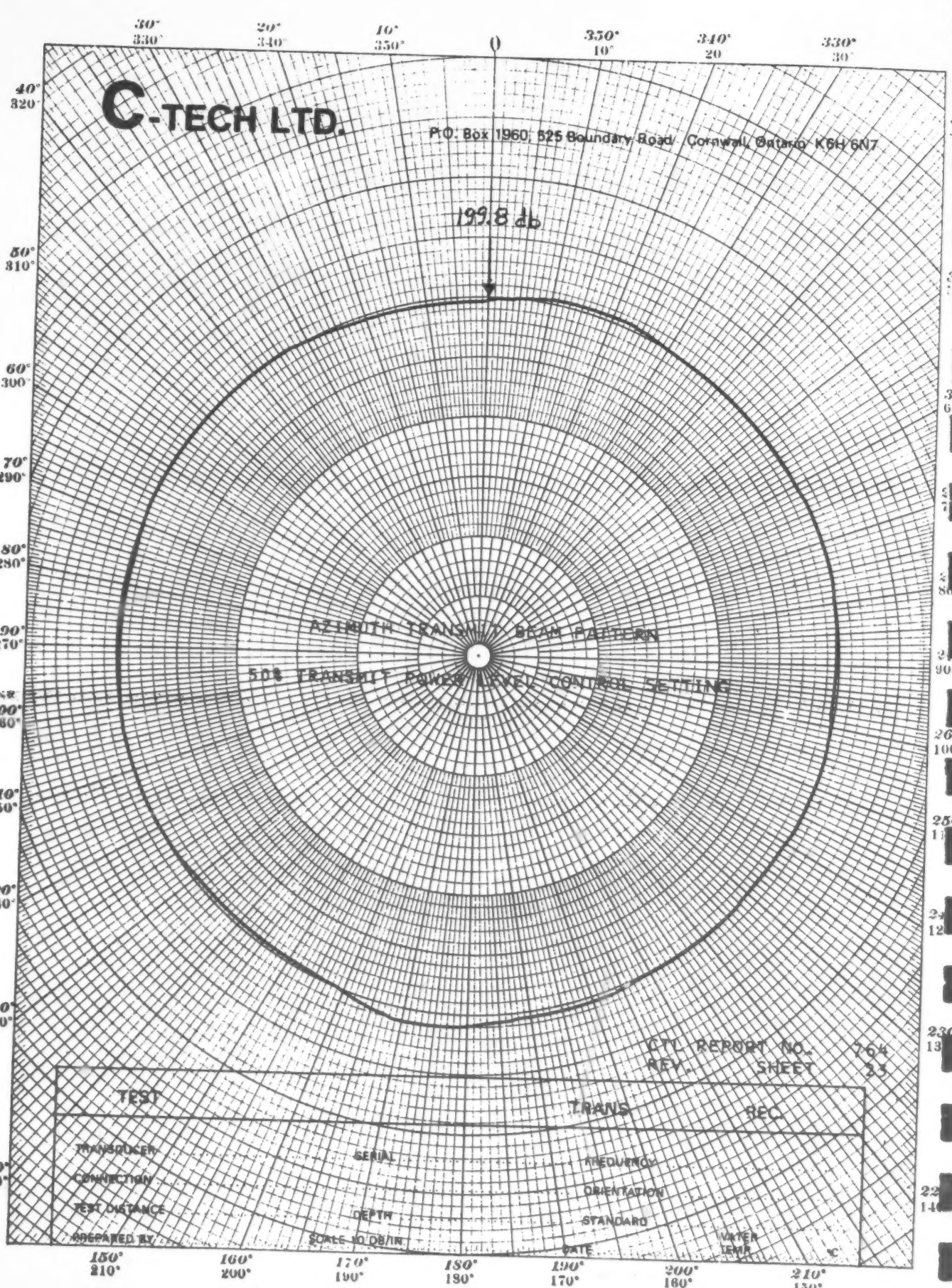
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario K6H 6N7
199.8 db
AZIMUTH TRANSMIT BEAM PATTERN
50% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO.
REV.
SHEET
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN.
DATE
WATER TEMP.
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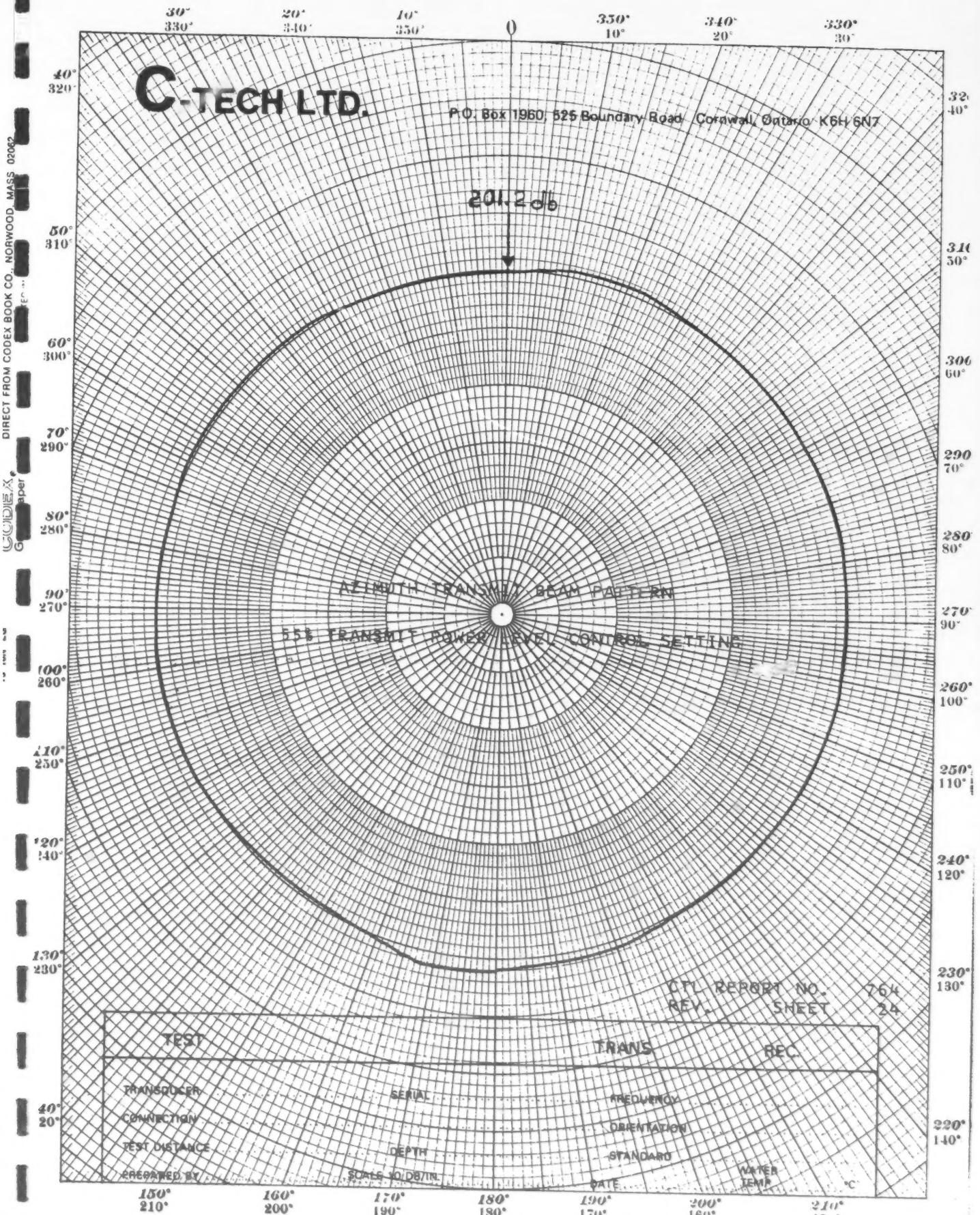
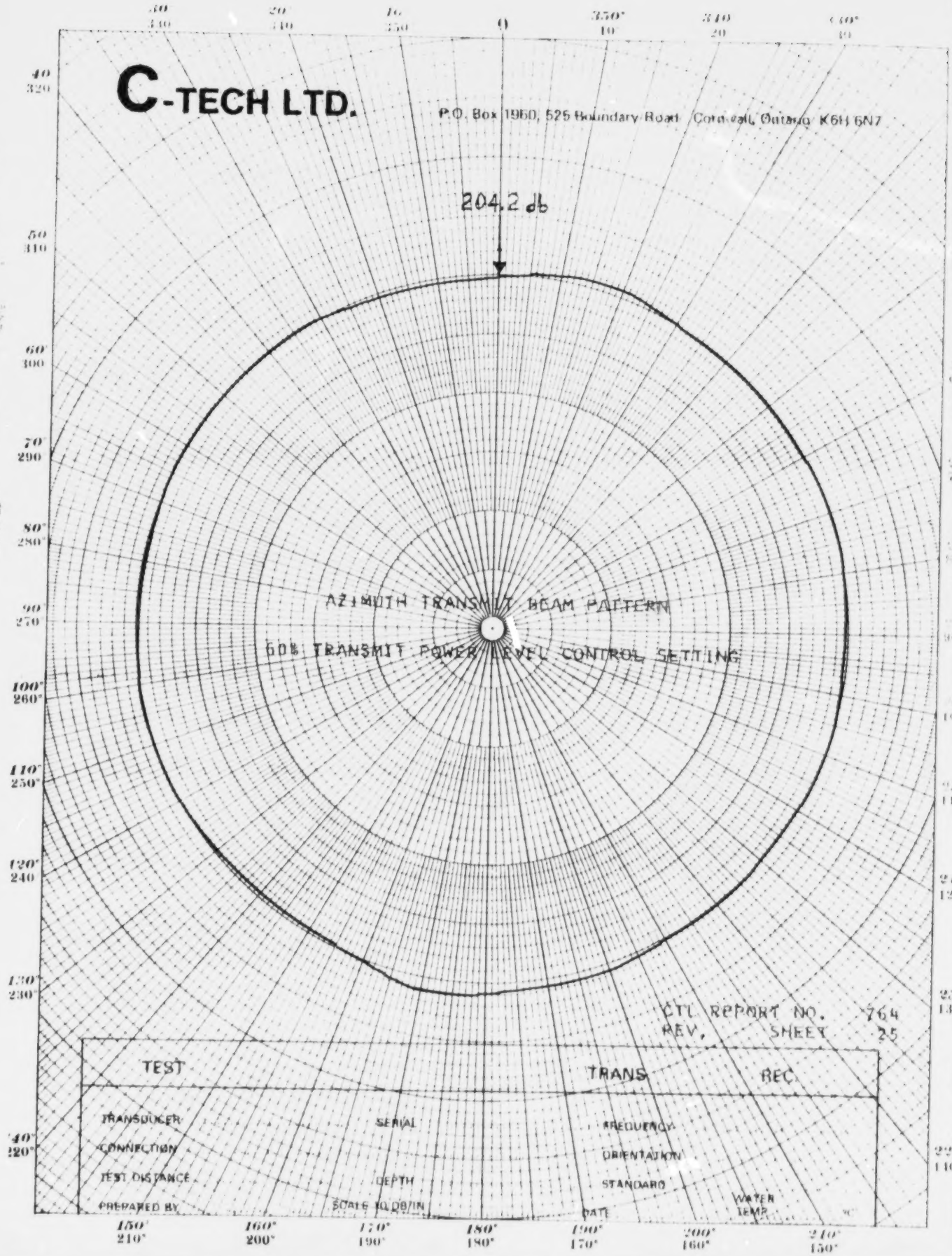


DIRECT FROM CODEX BOOK CO., NORWOOD, MASS. 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
204.2 db
AZIMUTH TRANSMIT BEAM PATTERN
60% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 25
TEST
TRANS
REC
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
STANDARD
DEPTH
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP
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30
40
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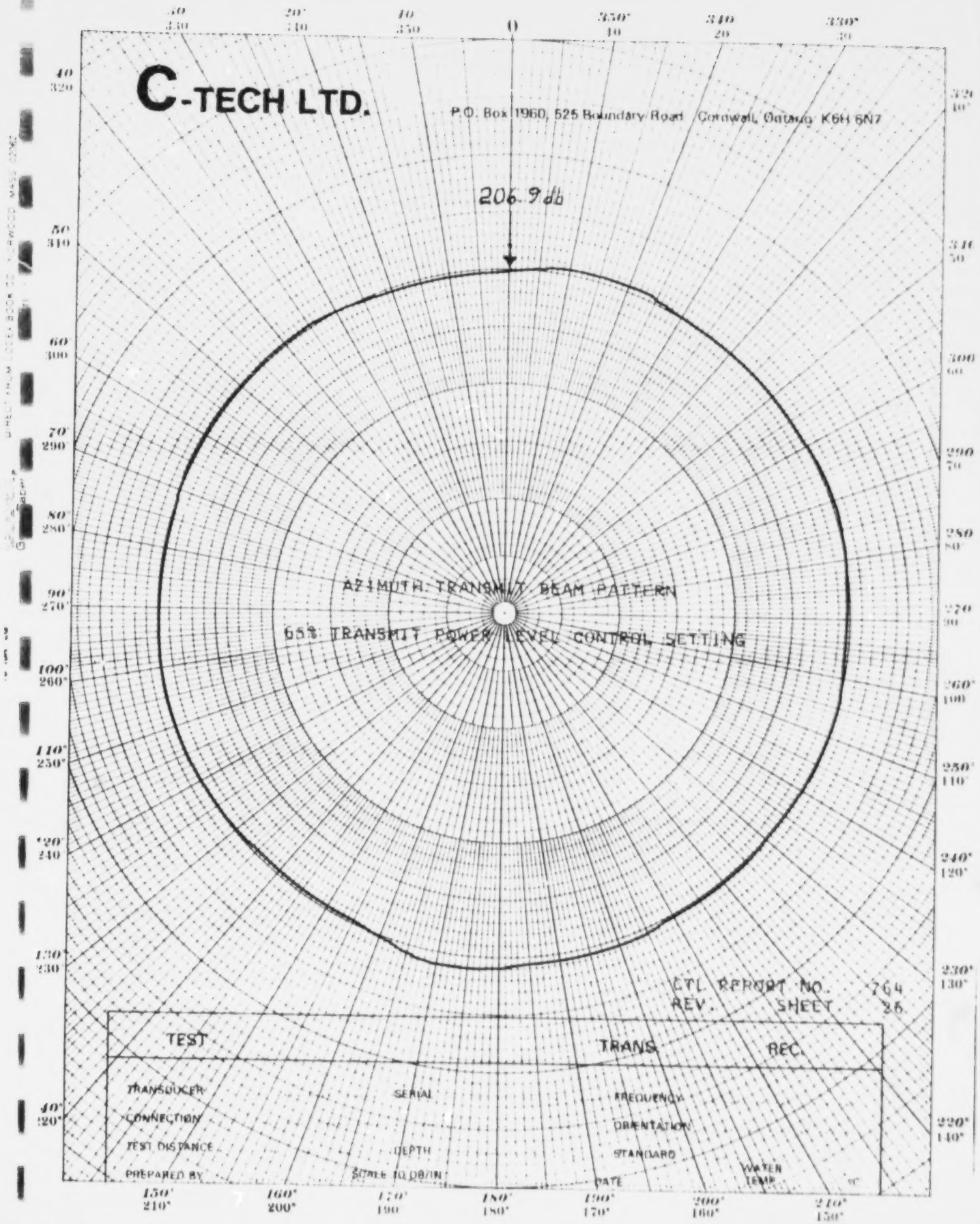
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
206.9 db
AZIMUTH TRANSMIT BEAM PATTERN
65% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 36
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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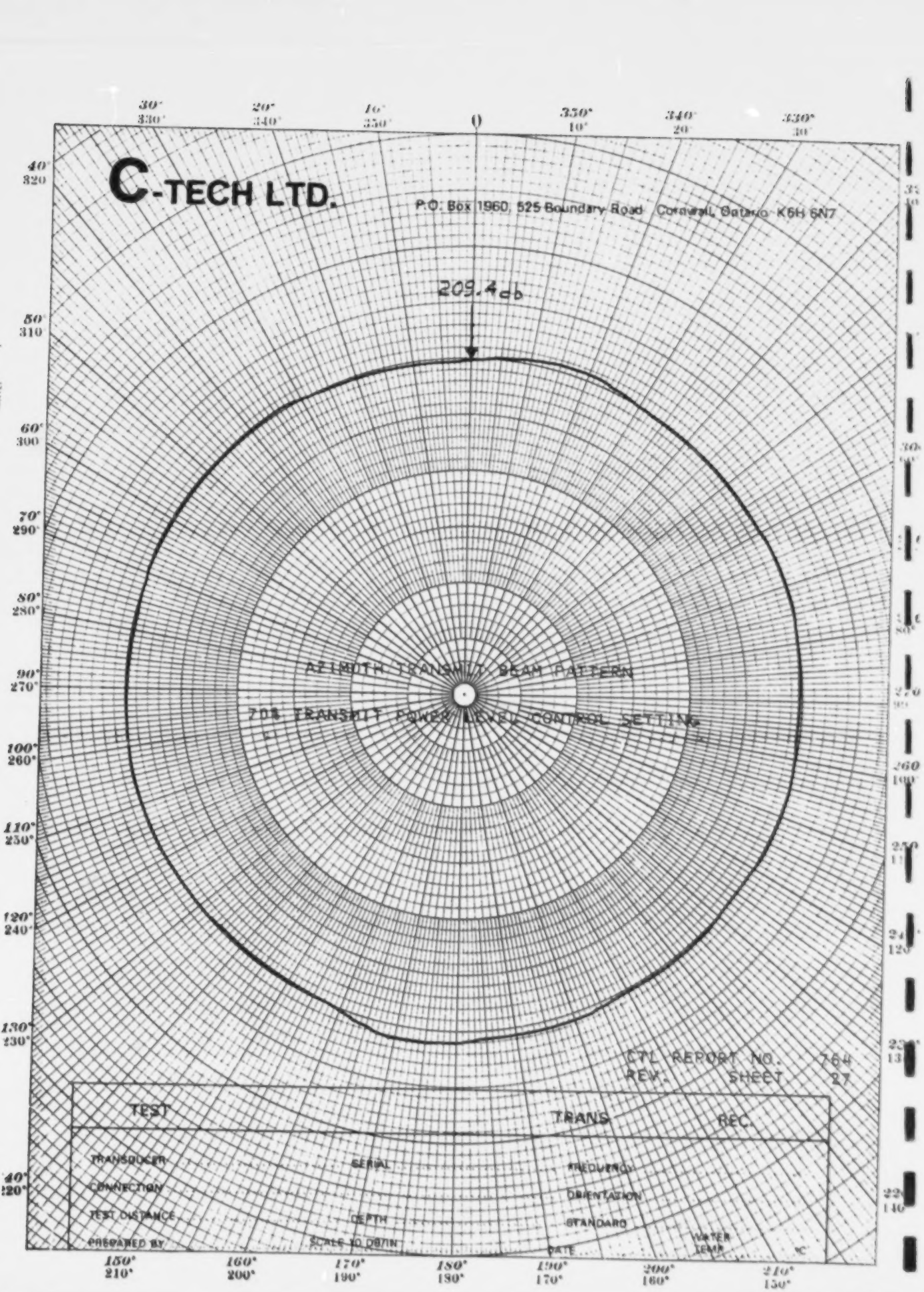
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
209.4db
AZIMUTH TRANSMIT BEAM PATTERN
70% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 27
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TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
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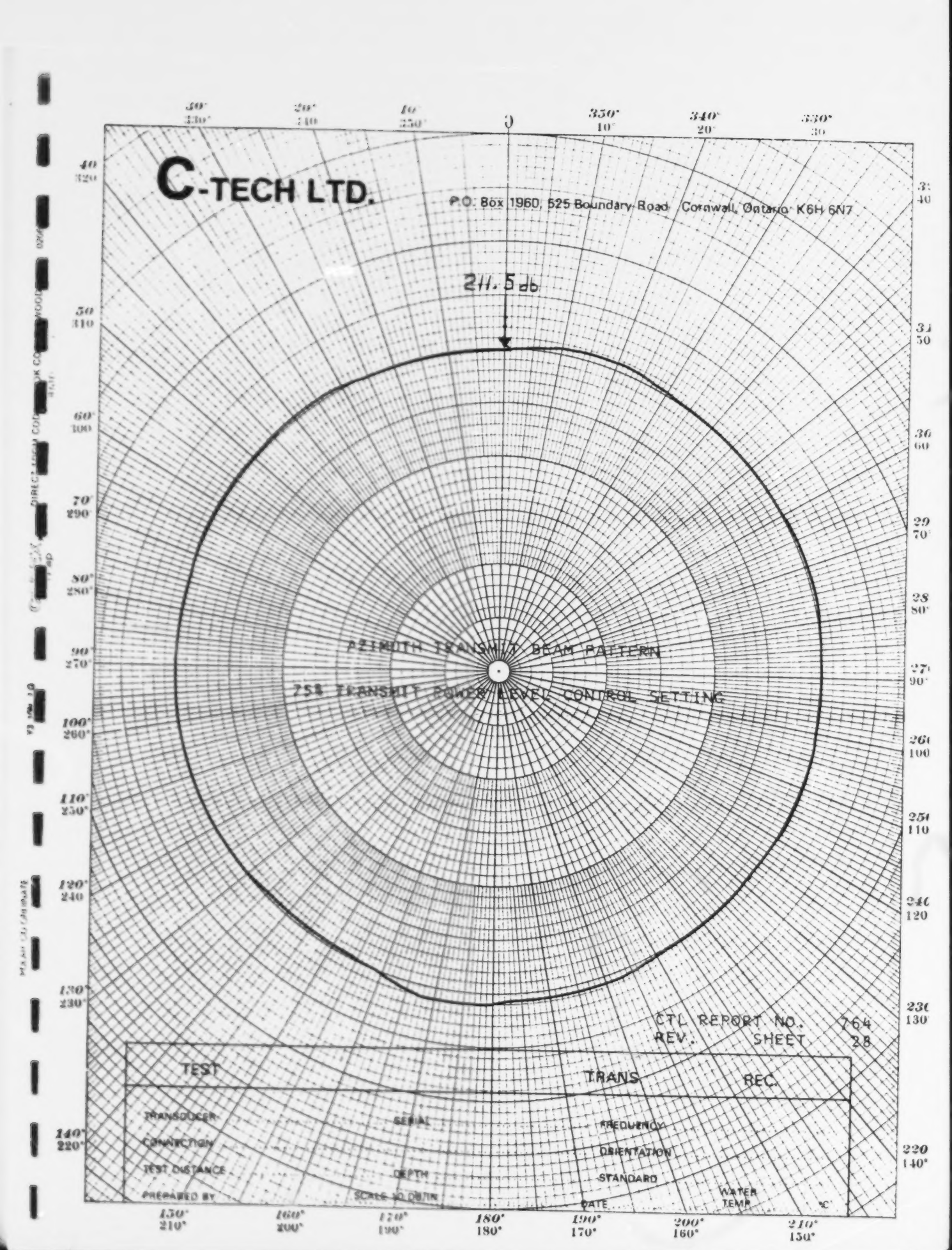
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
211.5 db
AZIMUTH TRANSMIT BEAM PATTERN
75% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 28
TEST
TRANS
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONFIGURATION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP °C
0° 360°
10° 350°
20° 340°
30° 330°
40° 320°
50° 310°
60° 300°
70° 290°
80° 280°
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170° 190°
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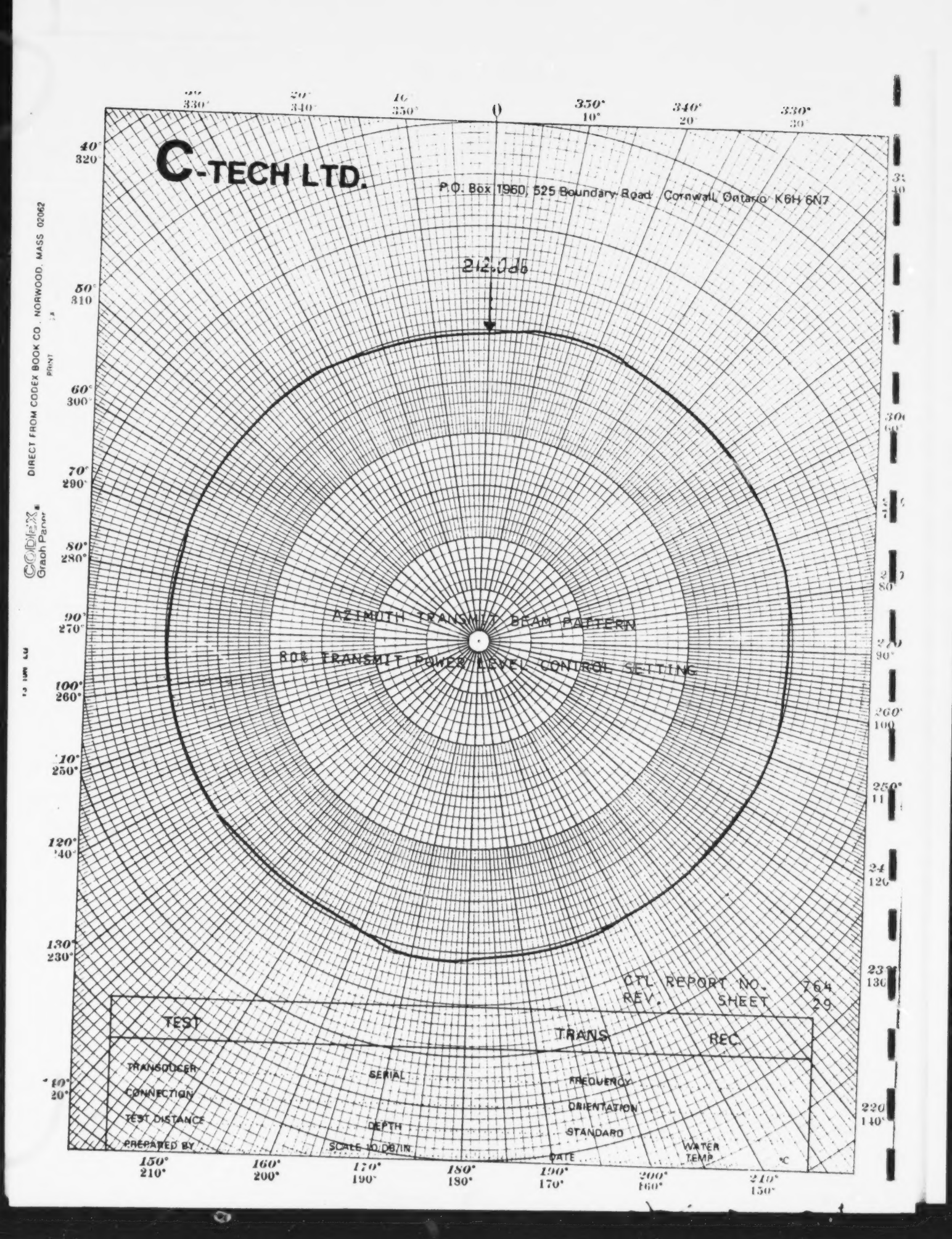
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
212.0db
AZIMUTH TRANSMIT BEAM PATTERN
80% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 29
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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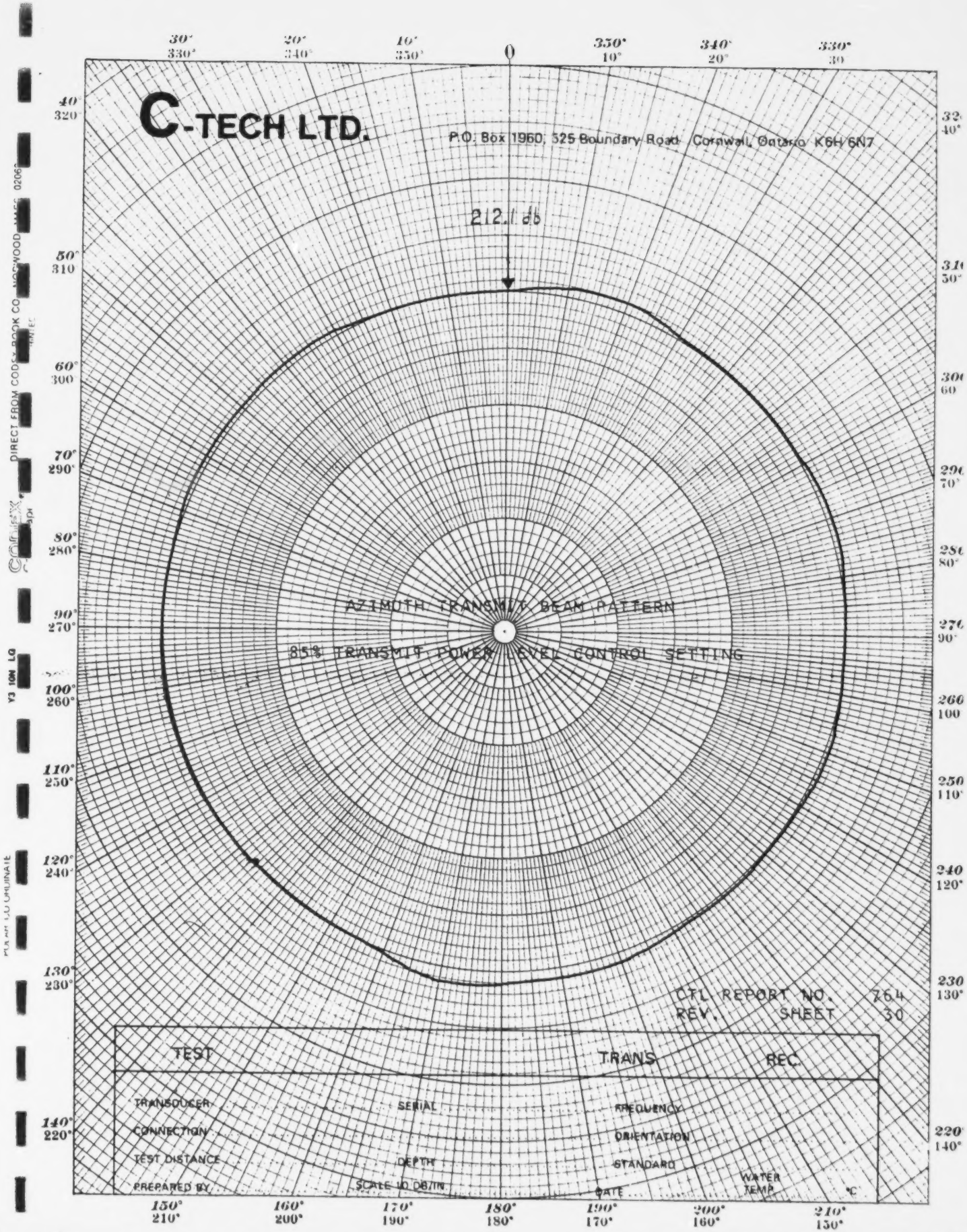
DIRECT FROM CODEX BOOK CO. NORWOOD, MASS 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
212.1 db
AZIMUTH TRANSMIT BEAM PATTERN
85% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 30
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP °C
0
10° 350°
20° 340°
30° 330°
40° 320°
50° 310°
60° 300°
70° 290°
80° 280°
90° 270°
100° 260°
110° 250°
120° 240°
130° 230°
140° 220°
150° 210°
160° 200°
170° 190°
180°
190° 170°
200° 160°
210° 150°
220° 140°
230° 130°
240° 120°
250° 110°
260° 100°
270° 90°
280° 80°
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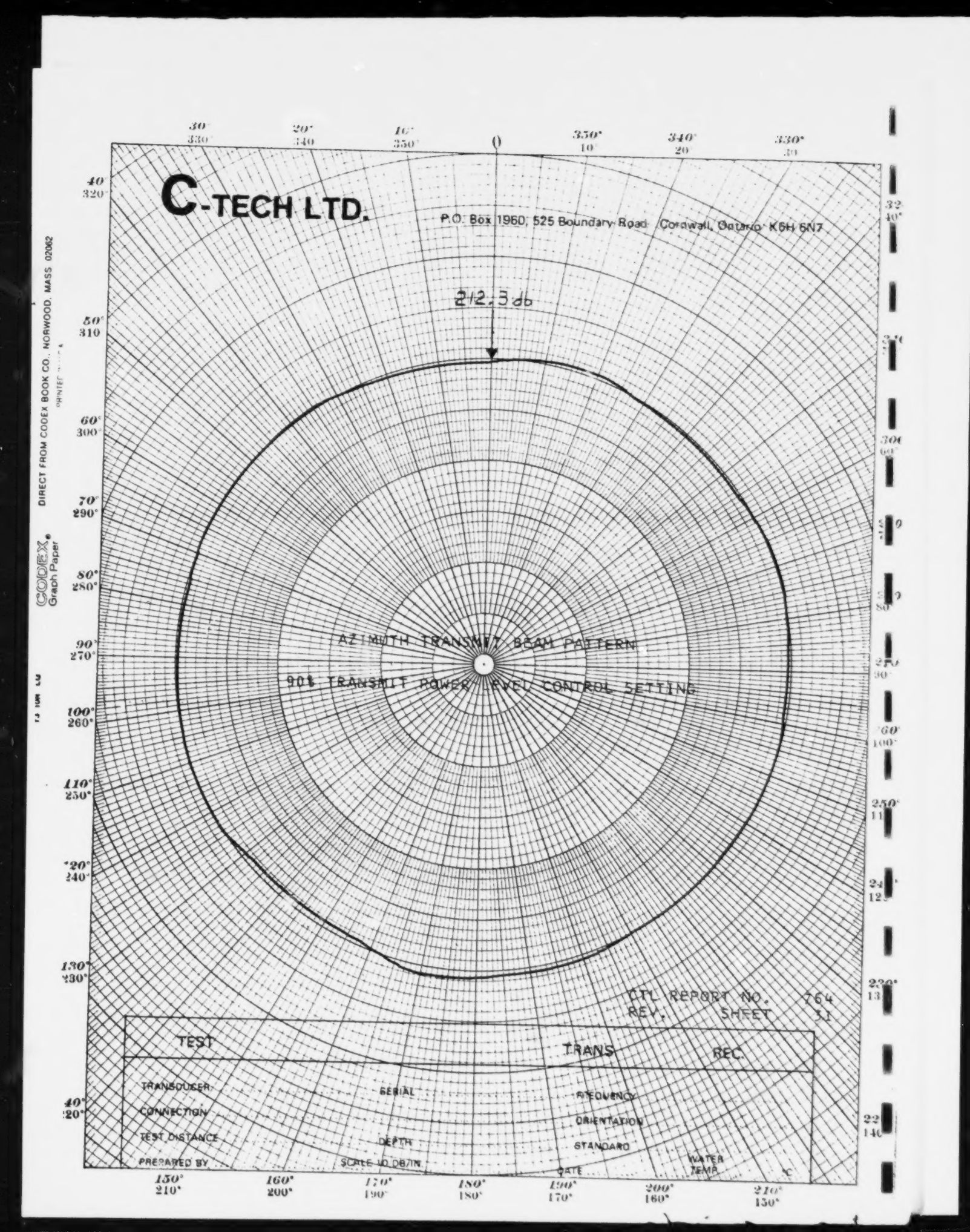
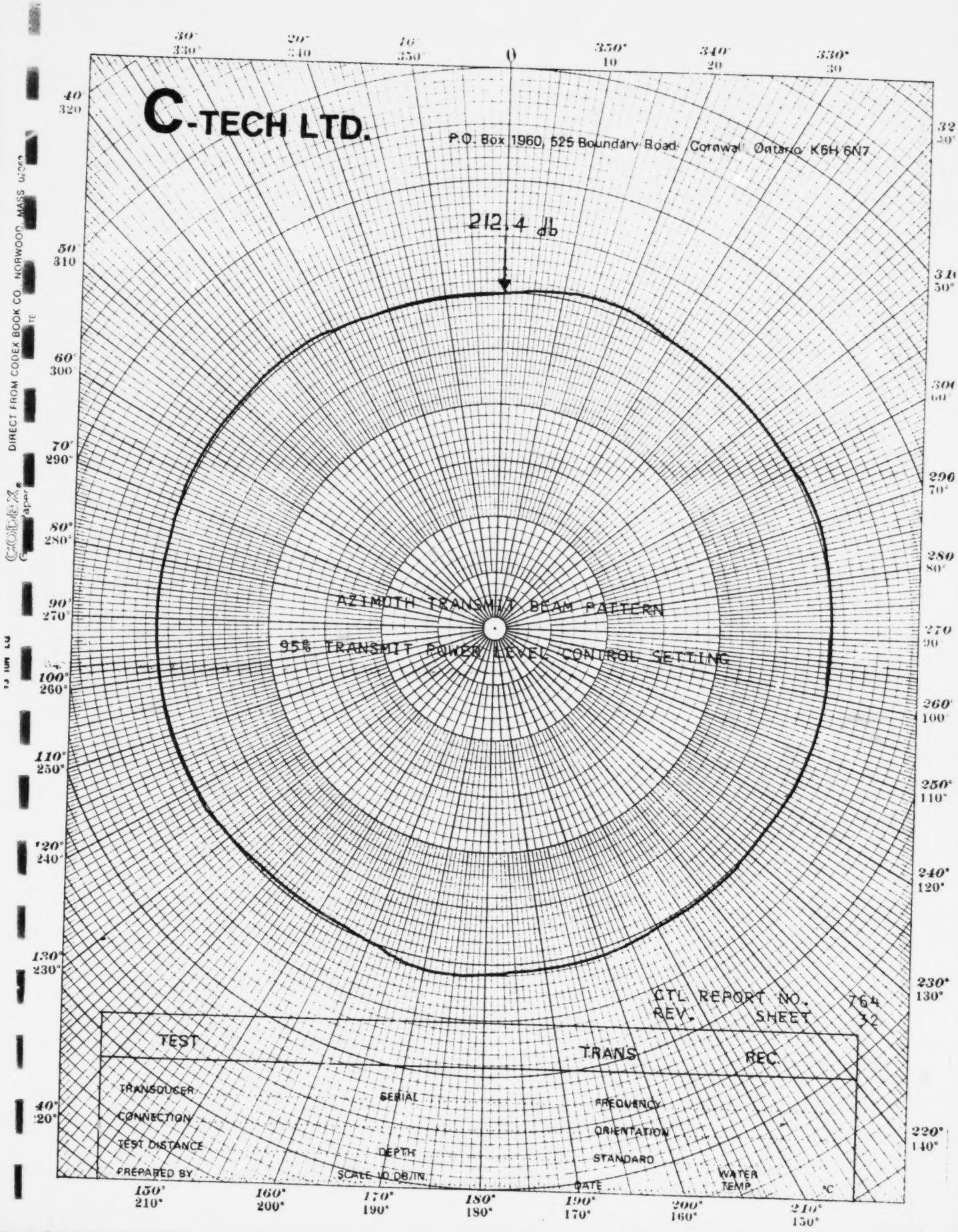
310° 50°
320° 40°
330° 30°
340° 20°
350° 10°


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
212.3db
AZIMUTH TRANSMIT BEAM PATTERN
90% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 31
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN.
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
°C
DIRECT FROM CODEX BOOK CO., NORWOOD, MASS 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall Ontario K6H 6N7
212.4 db
AZIMUTH TRANSMIT BEAM PATTERN
95% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV.
SHEET 32
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN.
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
°C
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10
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340
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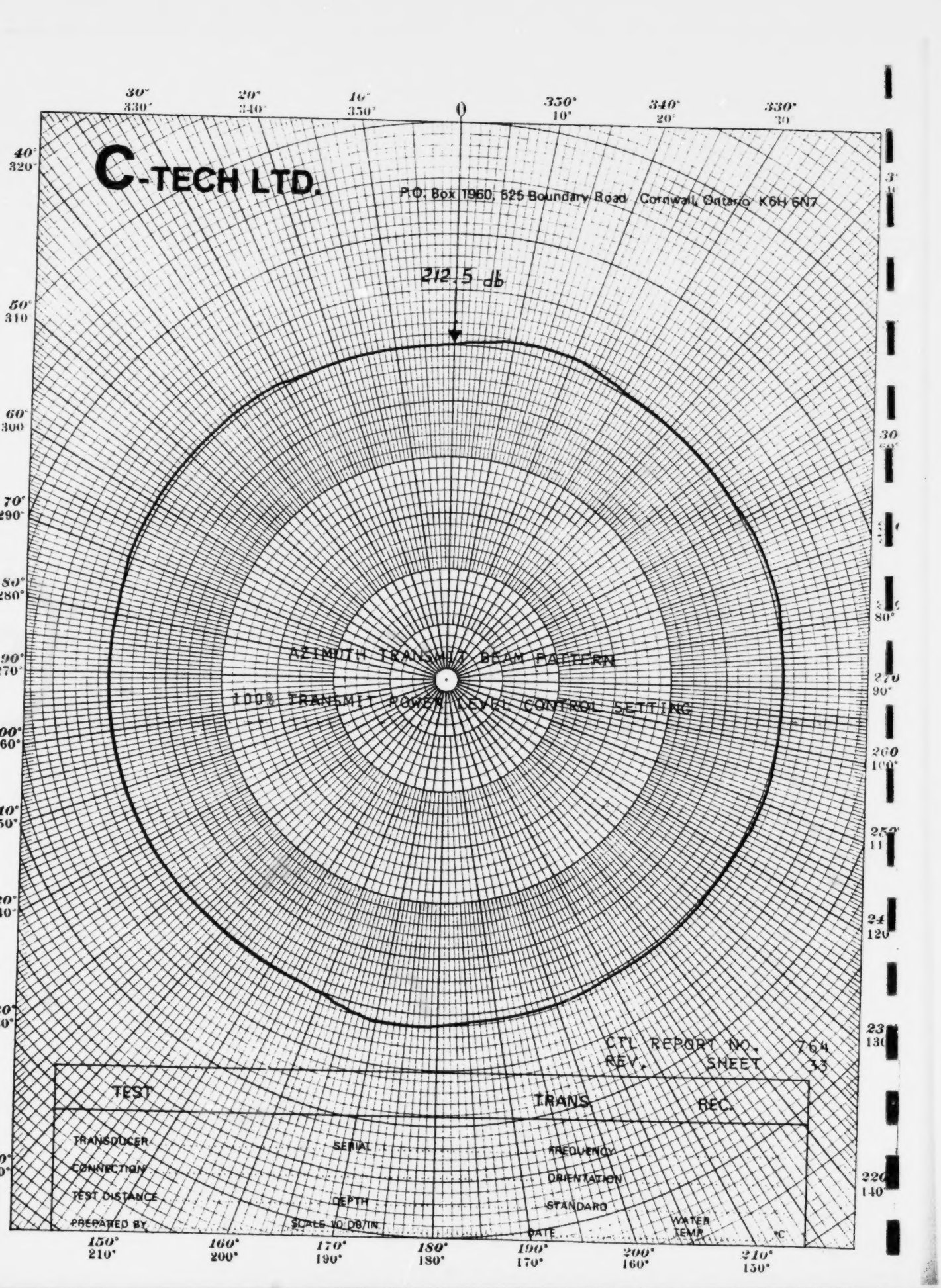
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
212.5 db
AZIMUTH TRANSMIT BEAM PATTERN
100% TRANSMIT POWER LEVEL CONTROL SETTING
CTL REPORT NO. 764
REV. SHEET 33
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
WATER TEMP °C
DATE
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70° 290°
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90° 270°
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170° 190°
180° 180°
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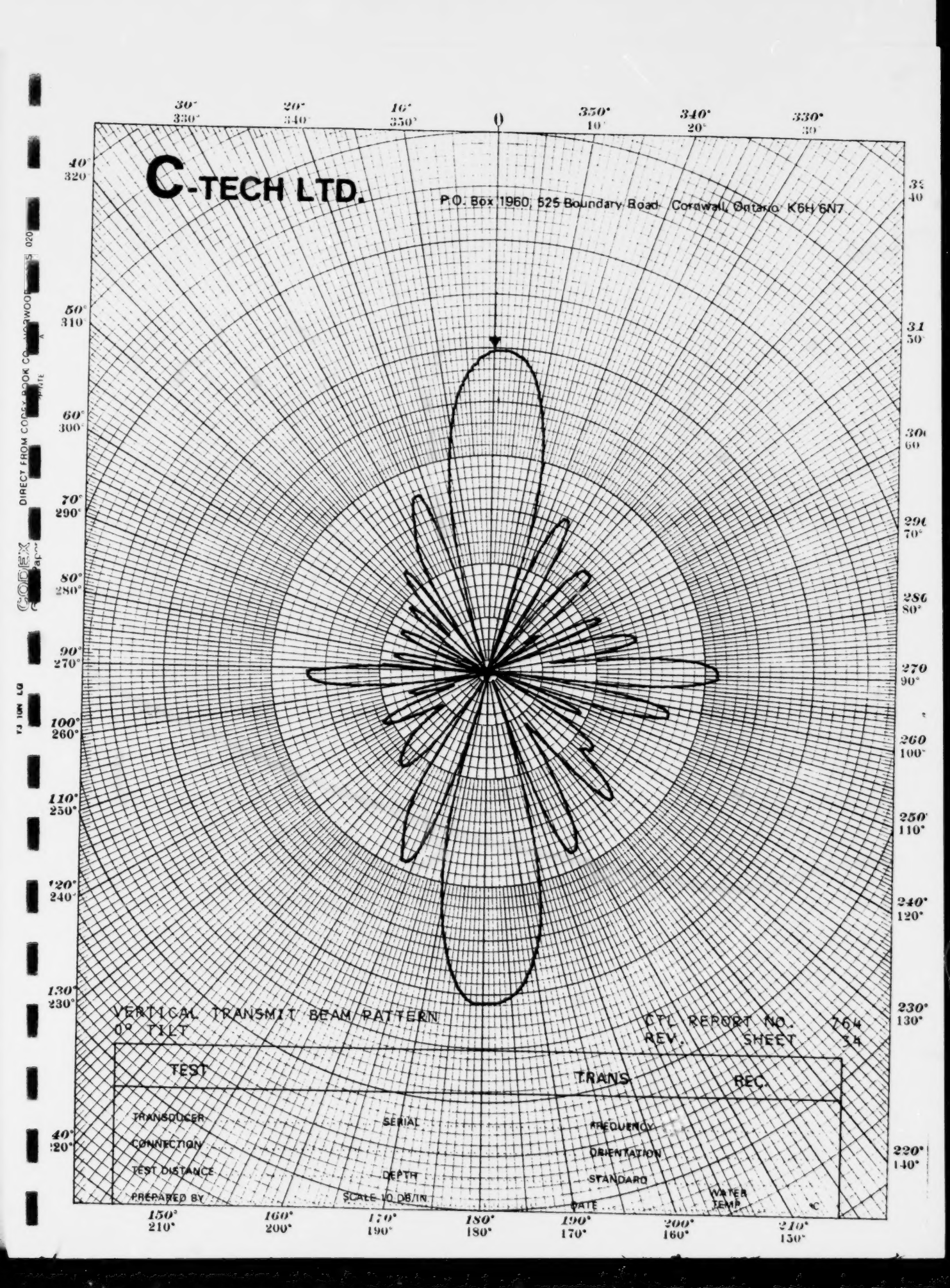
280° 80°


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
0° TILT
CPL REPORT NO. 764
REV.
SHEET 34
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP
°C
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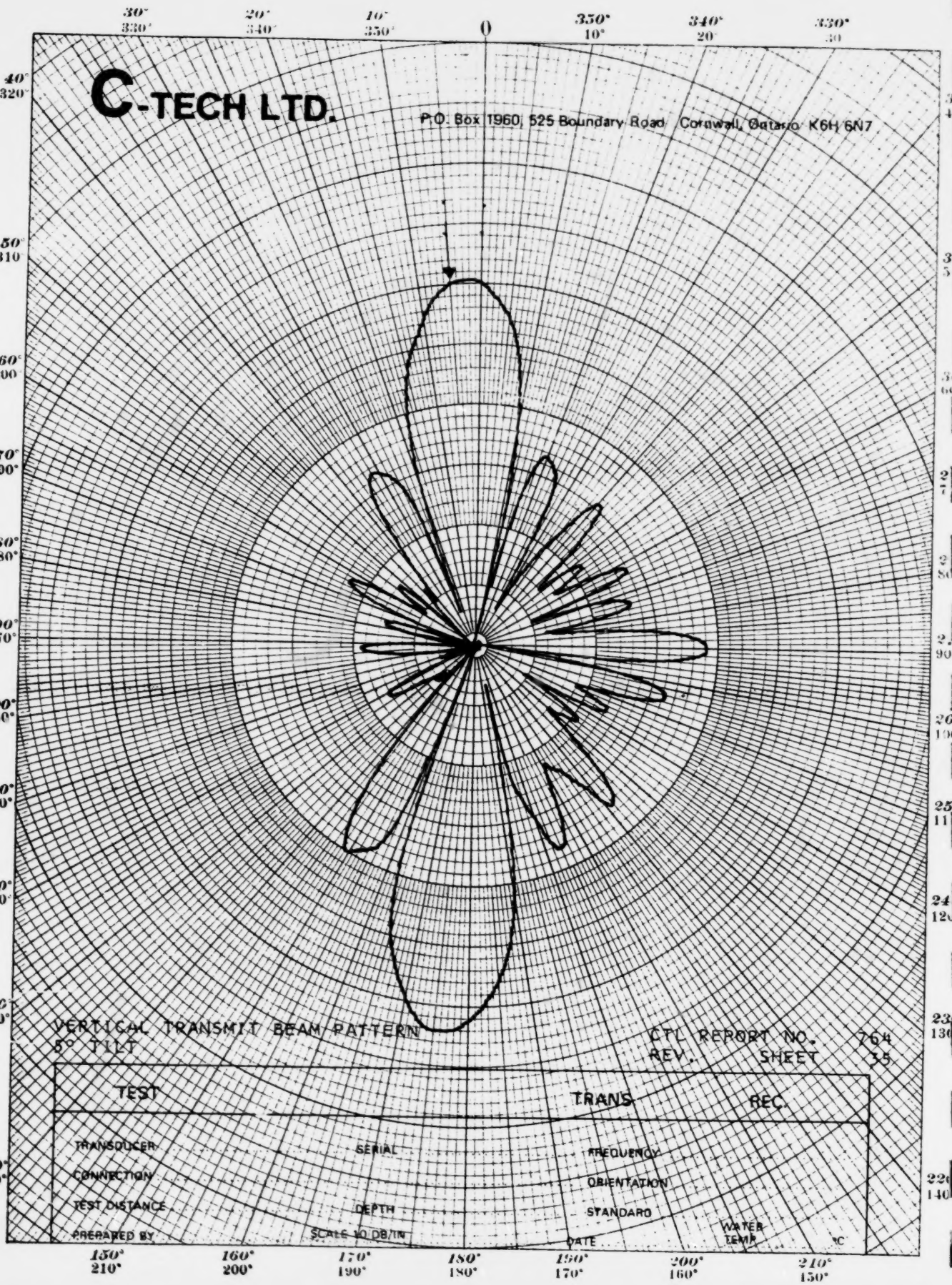
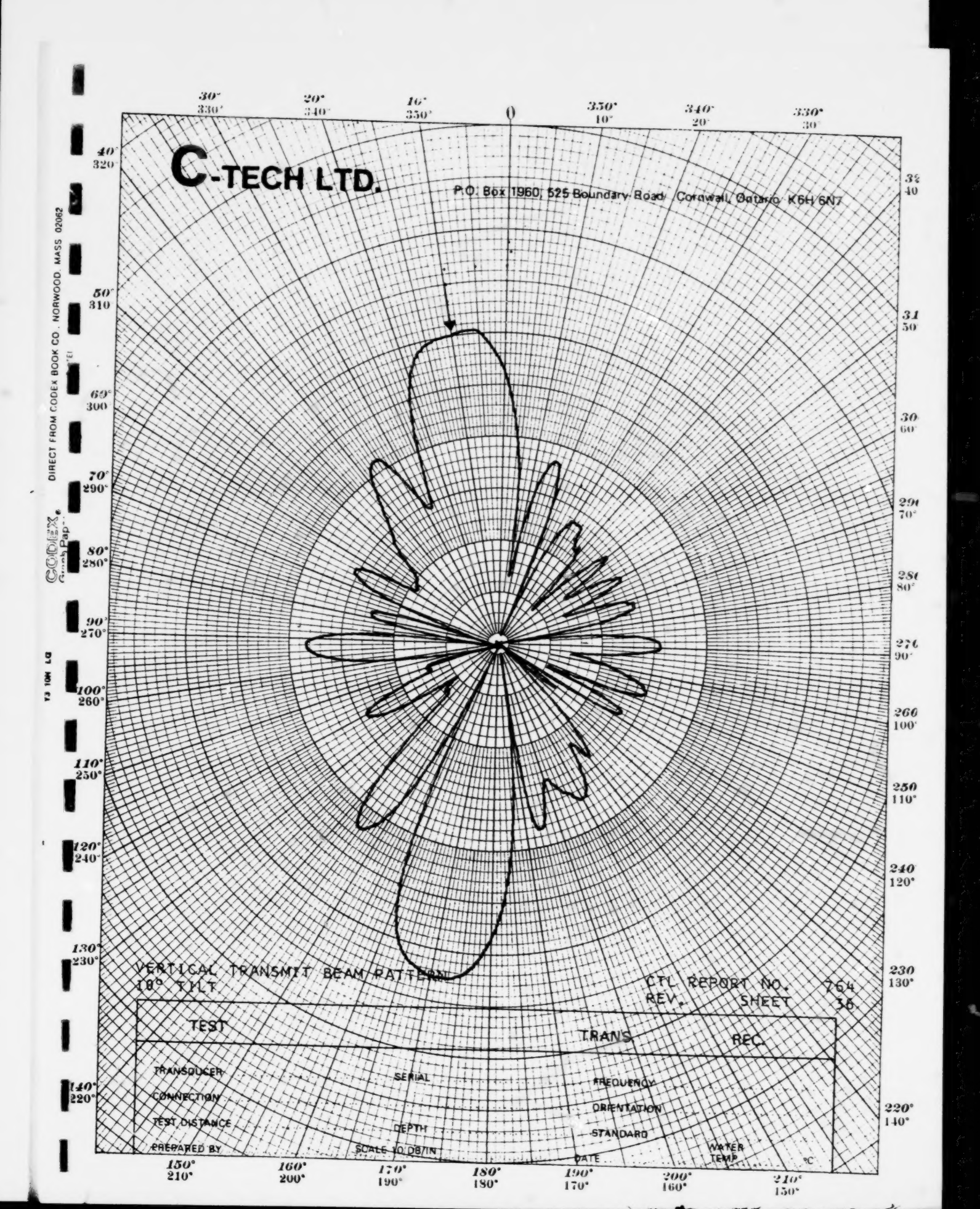


DIRECT FROM CODEX BOOK CO., NORWOOD, MASS. 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
10° TILT
CTL REPORT NO. 764
REV.
SHEET 36
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP
°C
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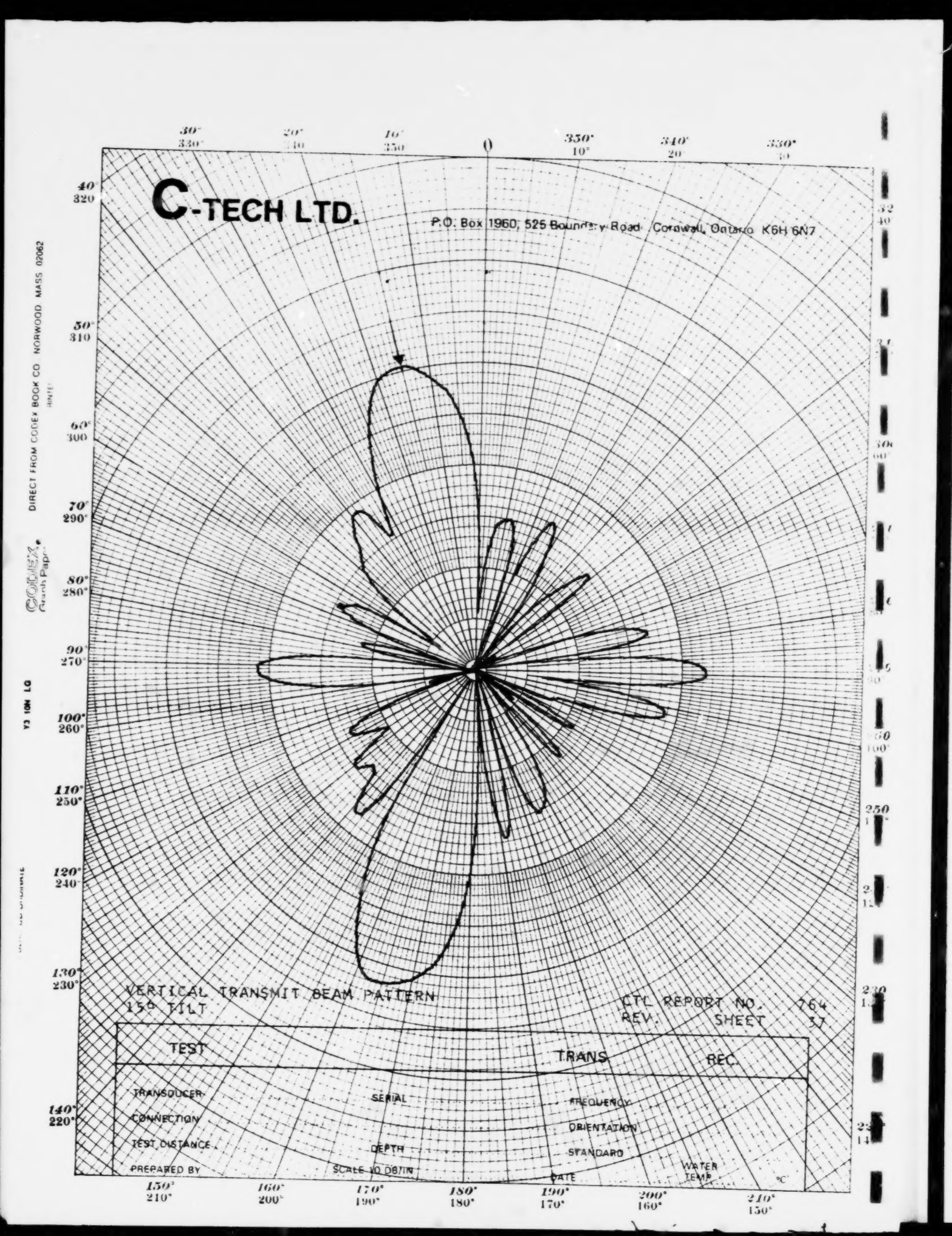
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
15° TILT
CTL REPORT NO. 764
REV.
SHEET 37
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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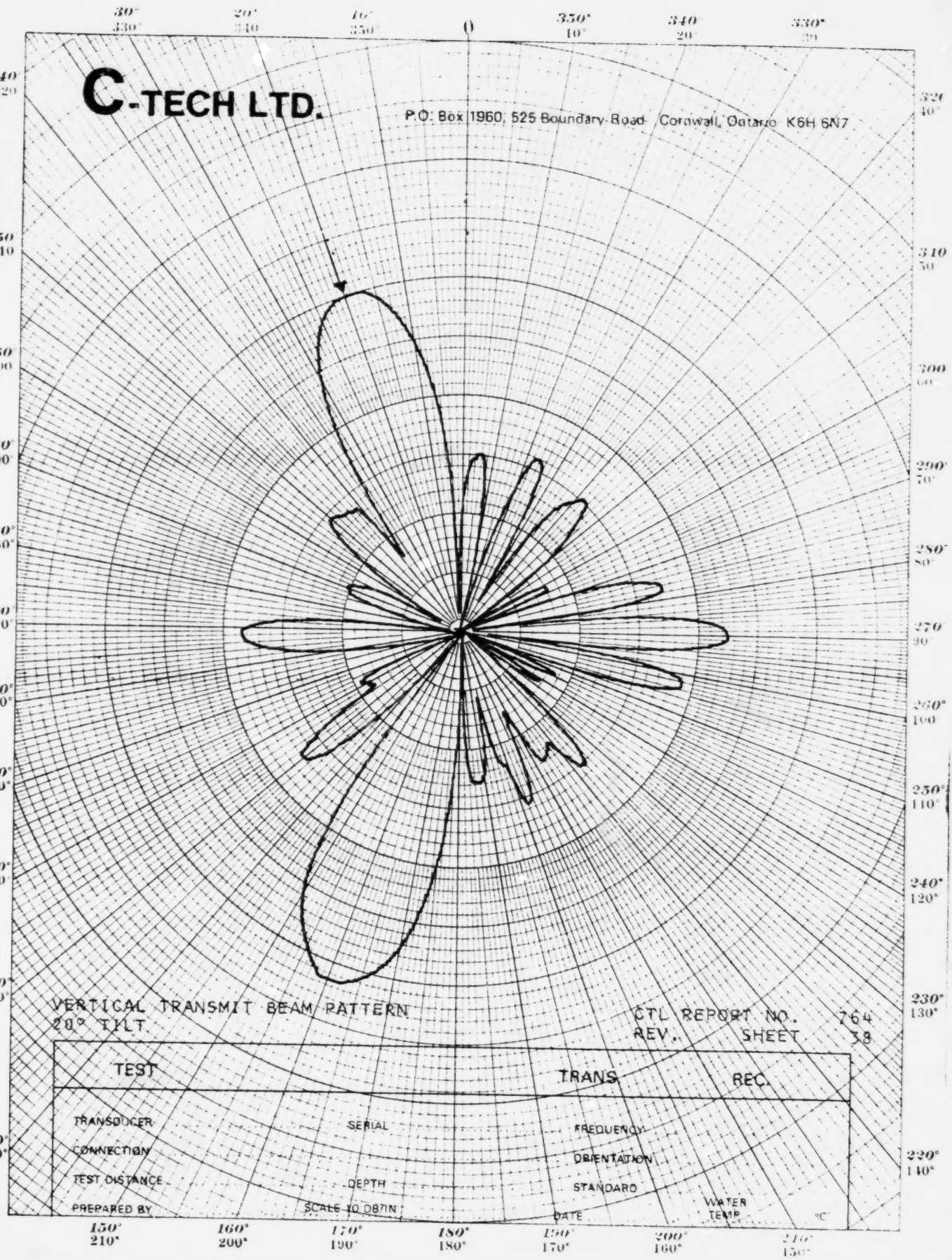
DIRECT FROM CODEX BOOK CO NORWOOD MASS 02062


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
20° TILT
CTL REPORT NO. 764
REV.
SHEET 38
TEST
TRANS
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP
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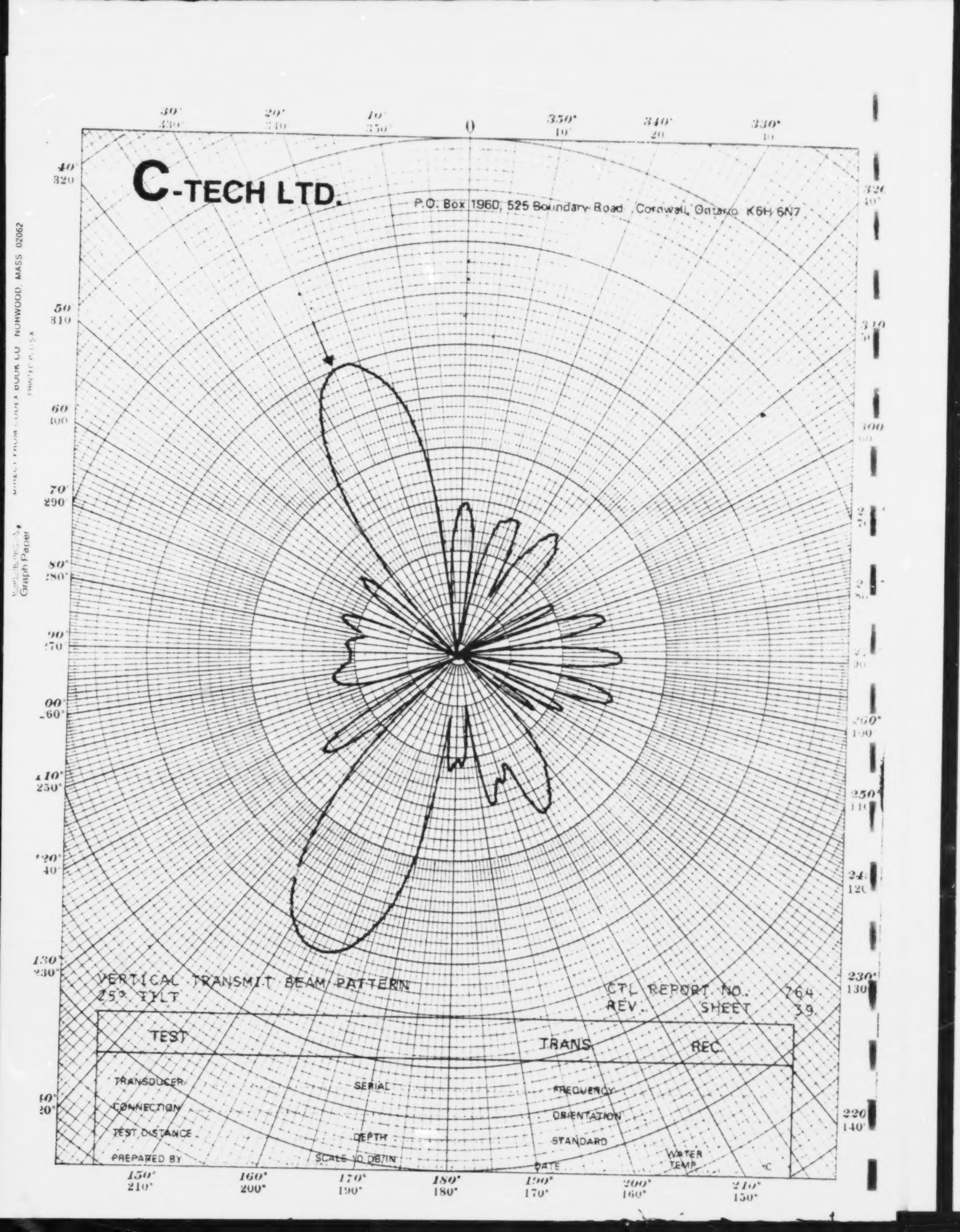
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
25° TILT
CTL REPORT NO. 764
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SHEET 39
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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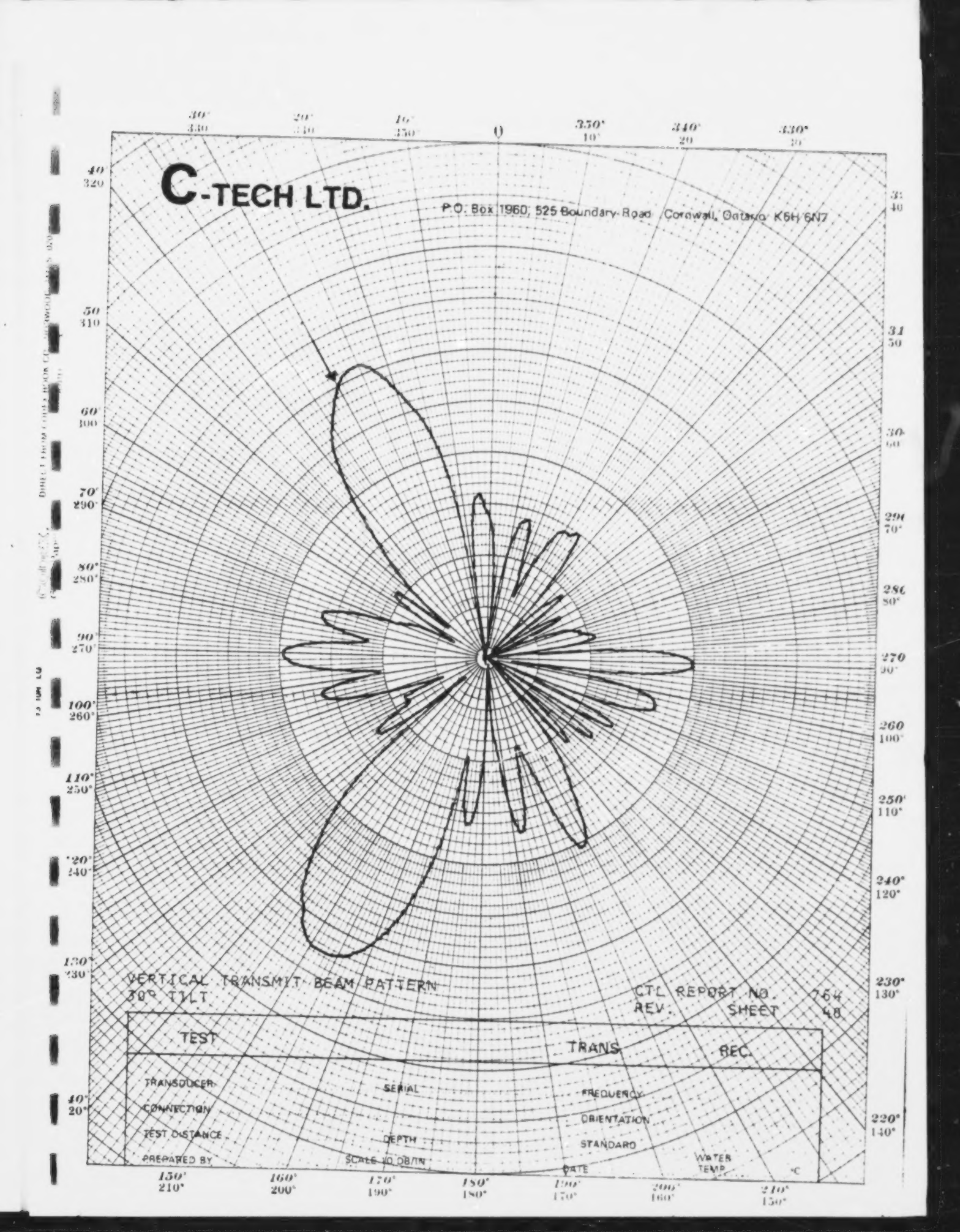
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
30° TILT
CTL REPORT NO. 754
REV.
SHEET 48
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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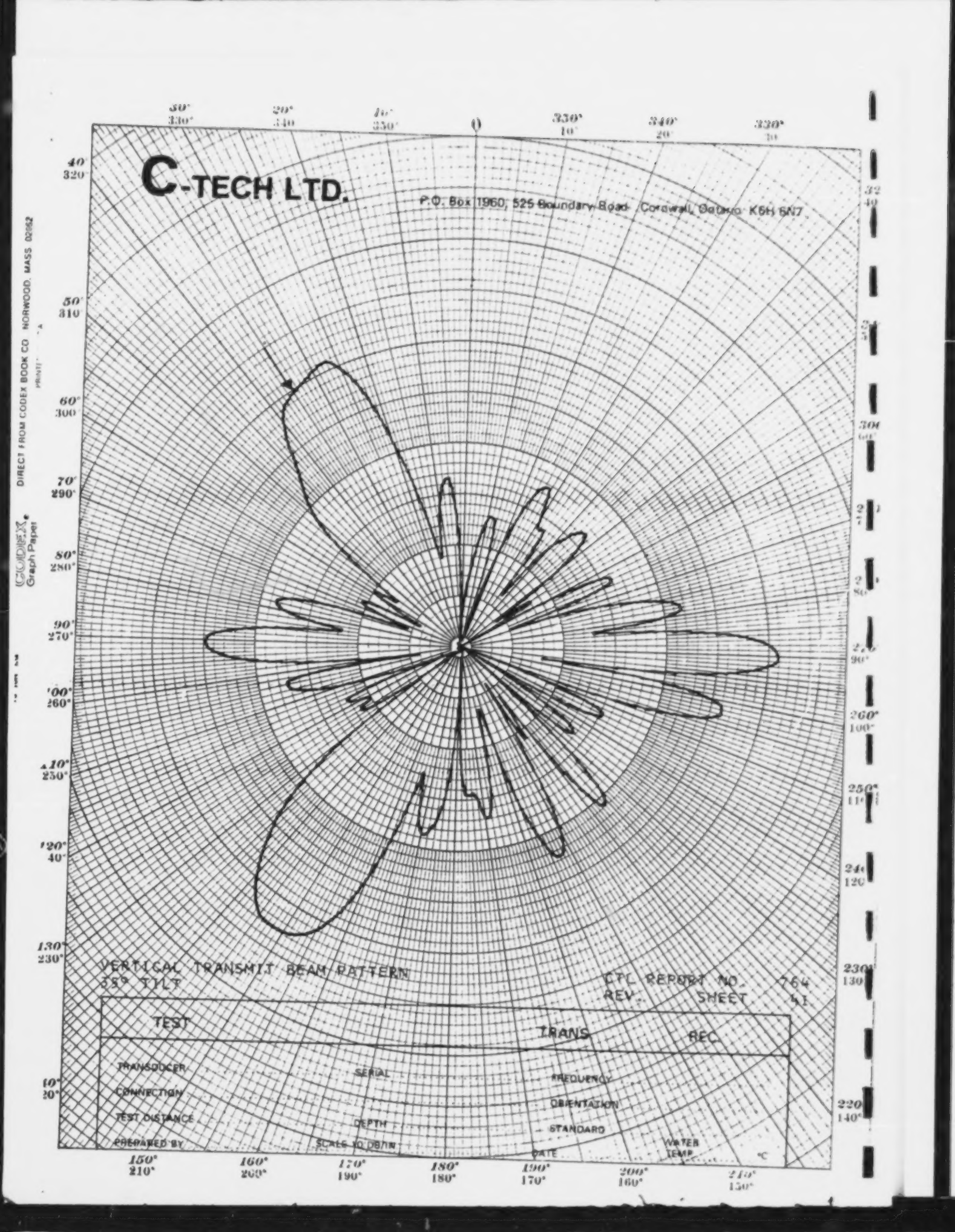
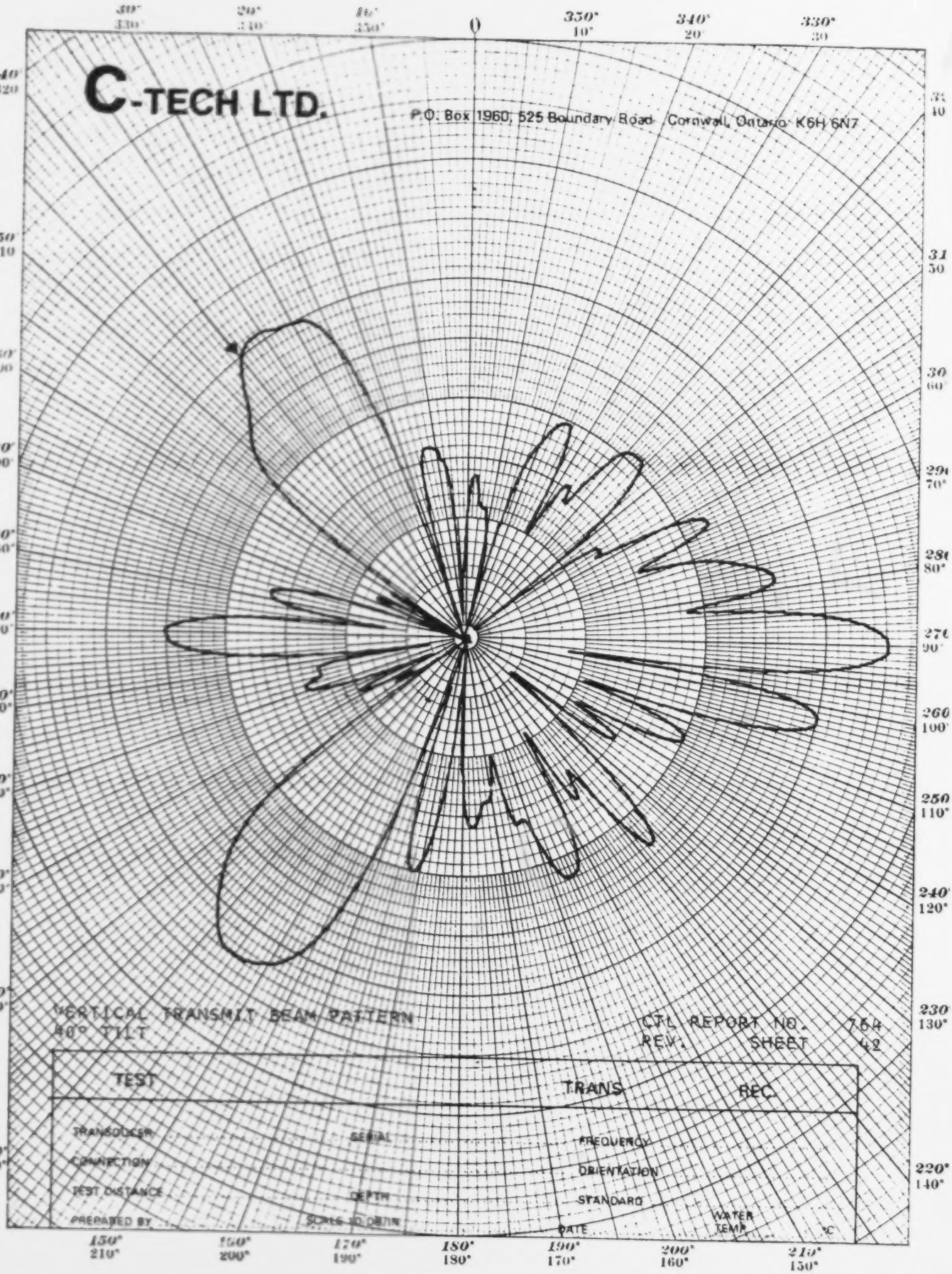

C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
55° TILT
CTL REPORT NO. 764
REV.
SHEET 41
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
°C
DIRECT FROM CODEX BOOK CO NORWOOD, MASS 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
40° TILT
CTL REPORT NO. 764
REV.
SHEET 42
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
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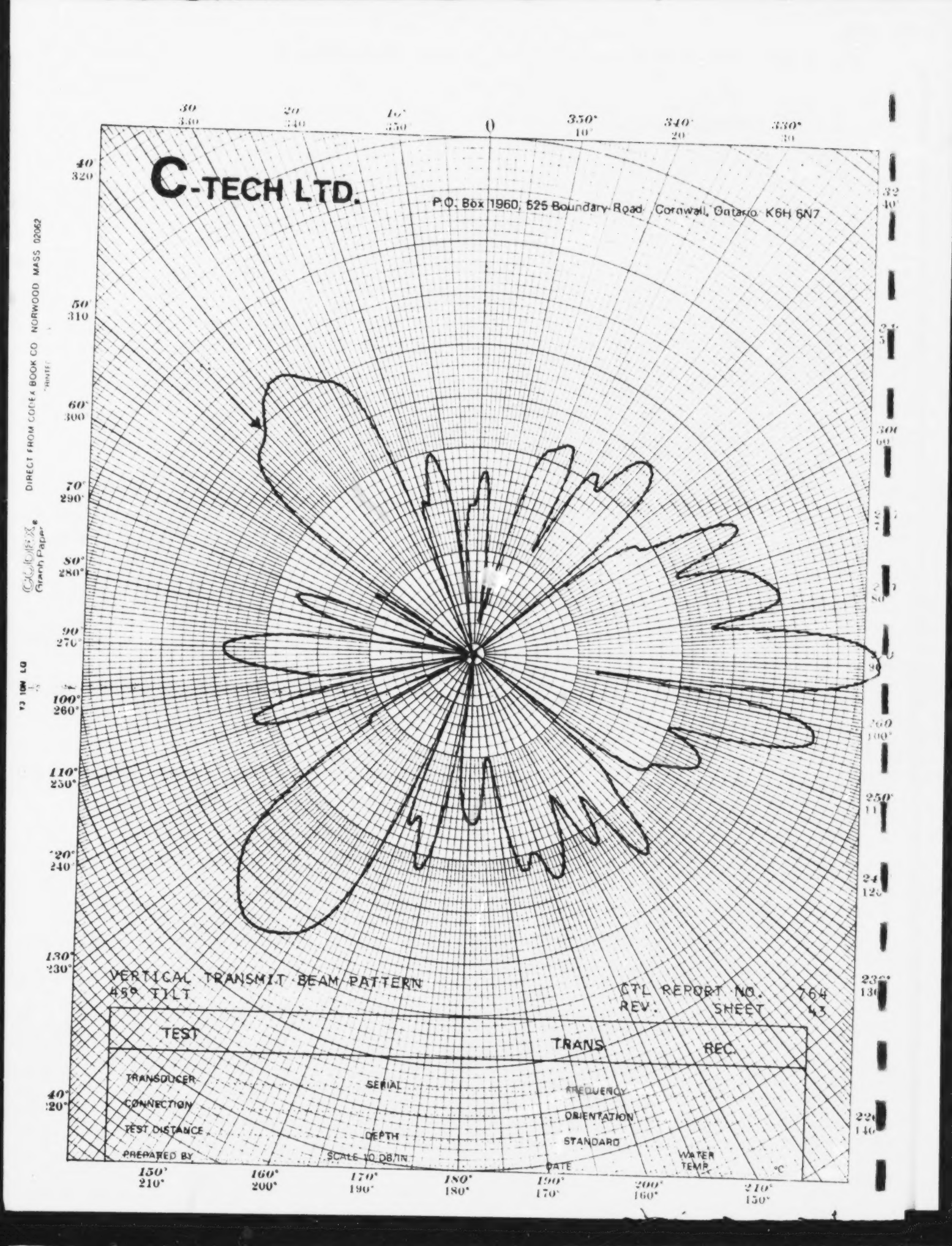
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL TRANSMIT BEAM PATTERN
45° TILT
CTL REPORT NO. 764
REV.
SHEET 43
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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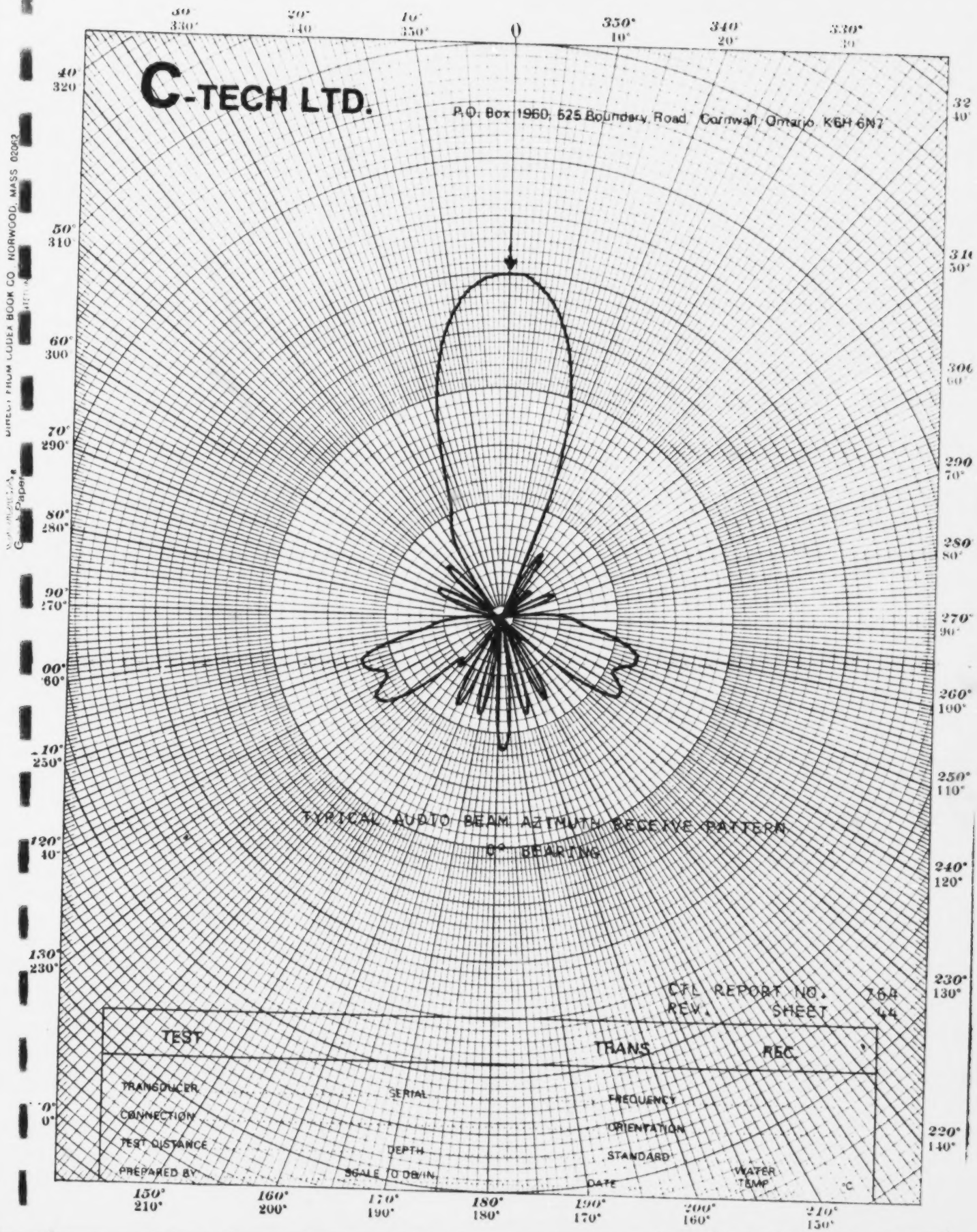
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
TYPICAL AUDIO BEAM AZIMUTH RECEIVE PATTERN
0° BEARING
CTL REPORT NO.
REV.
SHEET
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
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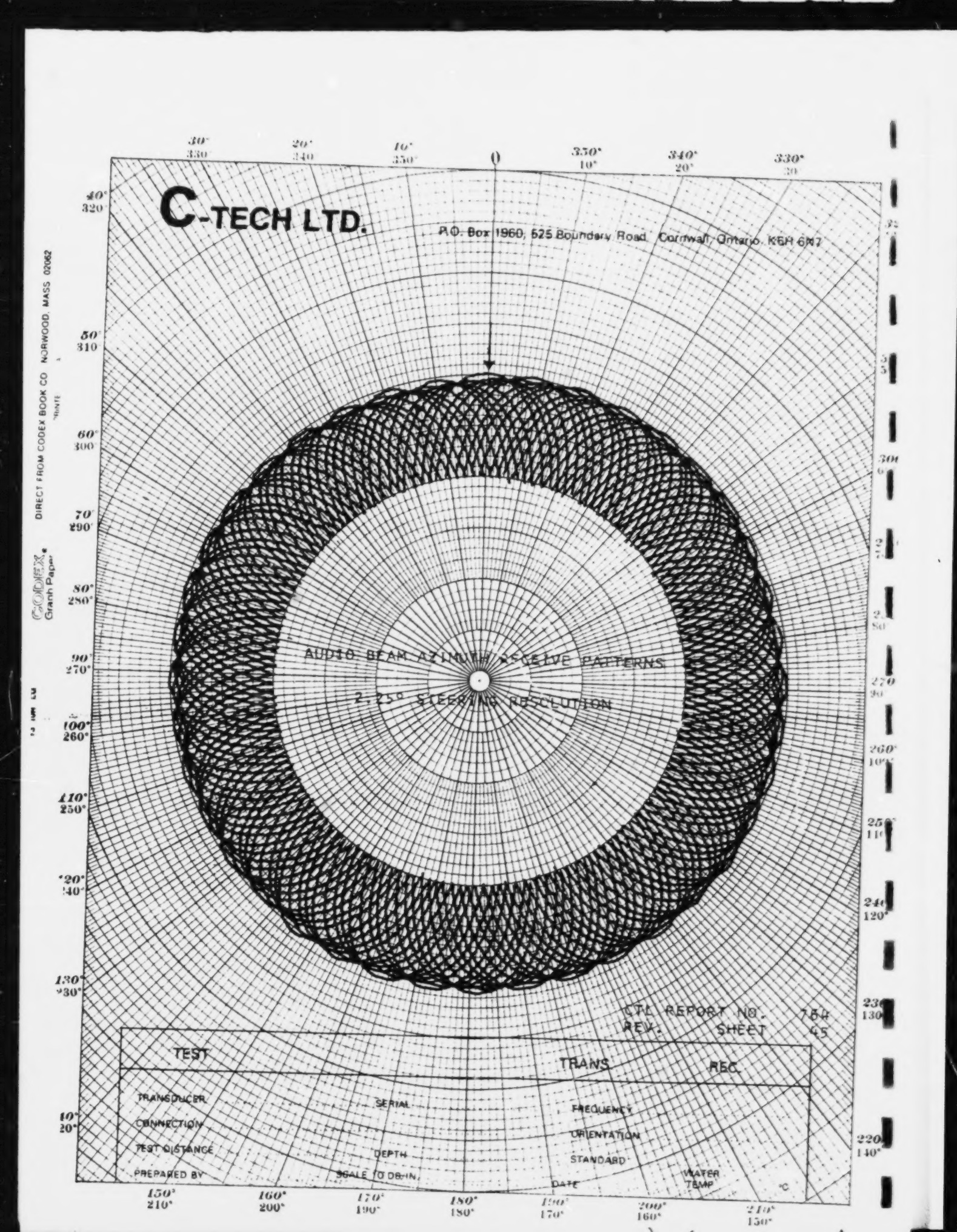
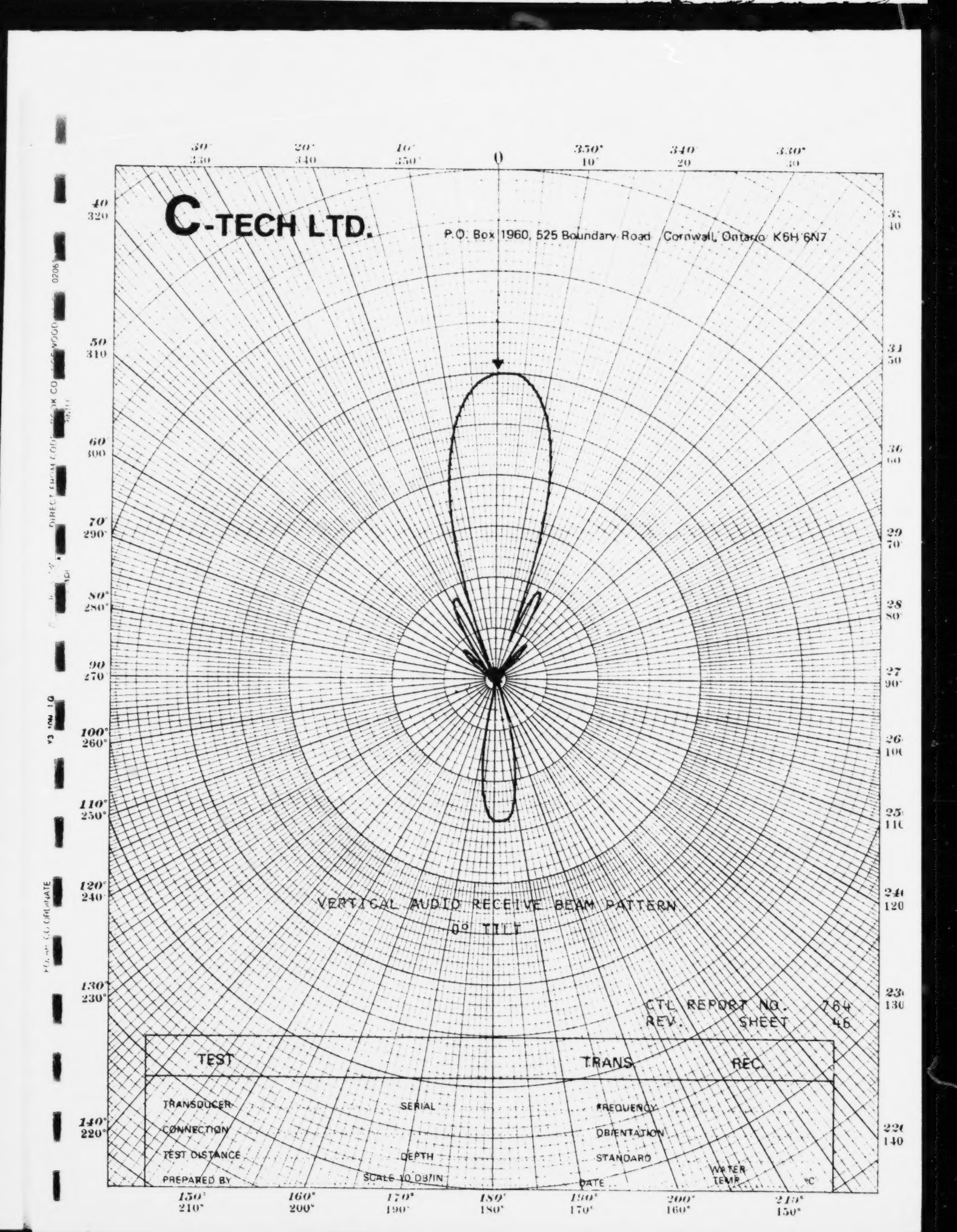
DEPTH
SCALE 10 DB/IN.
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
°C


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario, K6H 6N7
AUDIO BEAM AZIMUTH RECEIVE PATTERNS
2.25° STEERING RESOLUTION
CTL REPORT NO. 784
REV.
SHEET 45
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN.
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
°C
DIRECT FROM CODEX BOOK CO NORWOOD, MASS 02062
CODEX Graph Paper


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL AUDIO RECEIVE BEAM PATTERN
0° TILT
CTL REPORT NO. 764
REV. SHEET 46
TEST
TRANS.
REC.
TRANSDUCER
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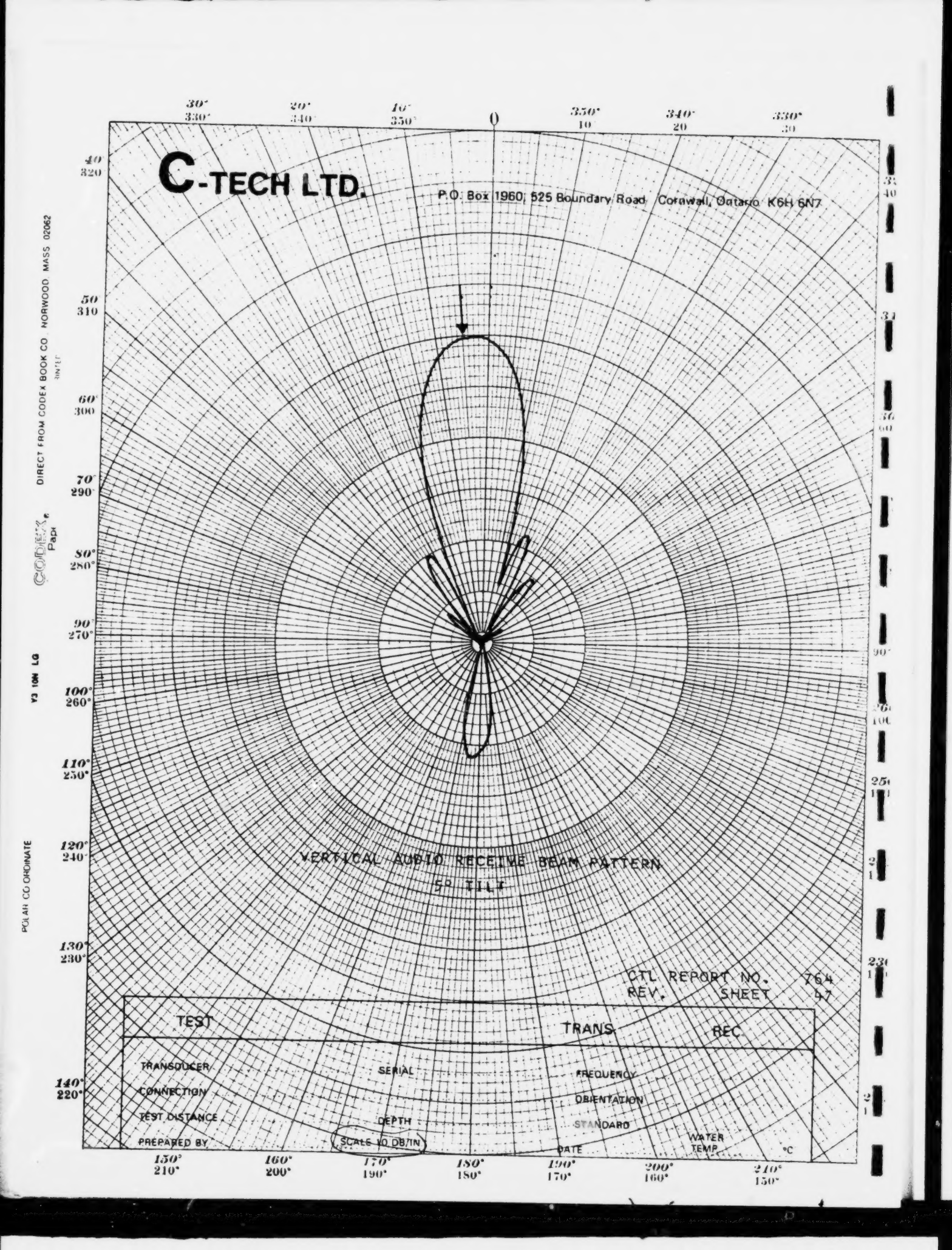
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP
°C


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL AUDIO RECEIVE BEAM PATTERN
5P TILT
CTL REPORT NO. 764
REV. SHEET 47
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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10° 350°
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330° 30
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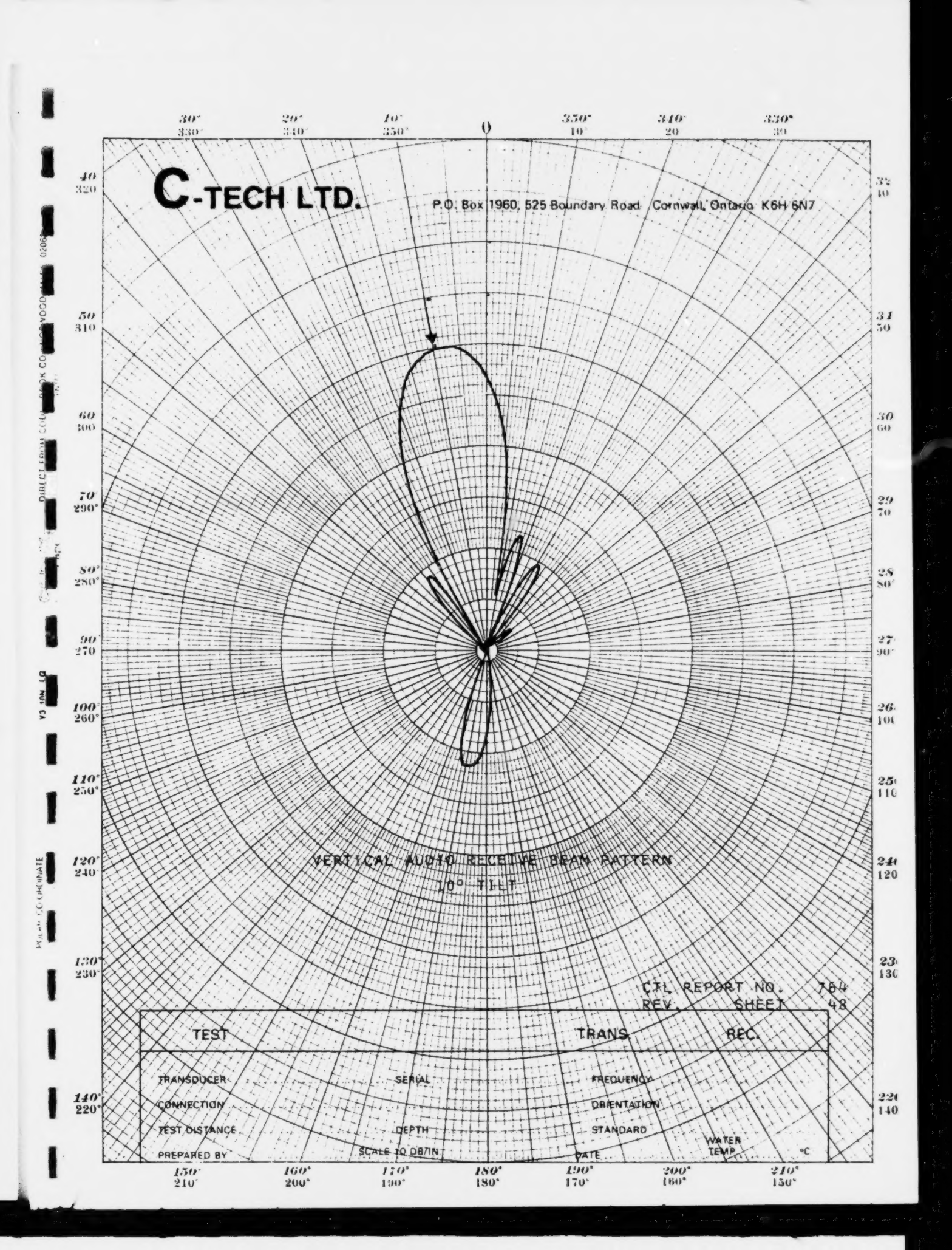
POLAR CO ORDINATE
DIRECT FROM CODEX BOOK CO NORWOOD MASS 02062


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL AUDIO RECEIVE BEAM PATTERN
10° TILT
CTL REPORT NO. 764
REV.
SHEET 48
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
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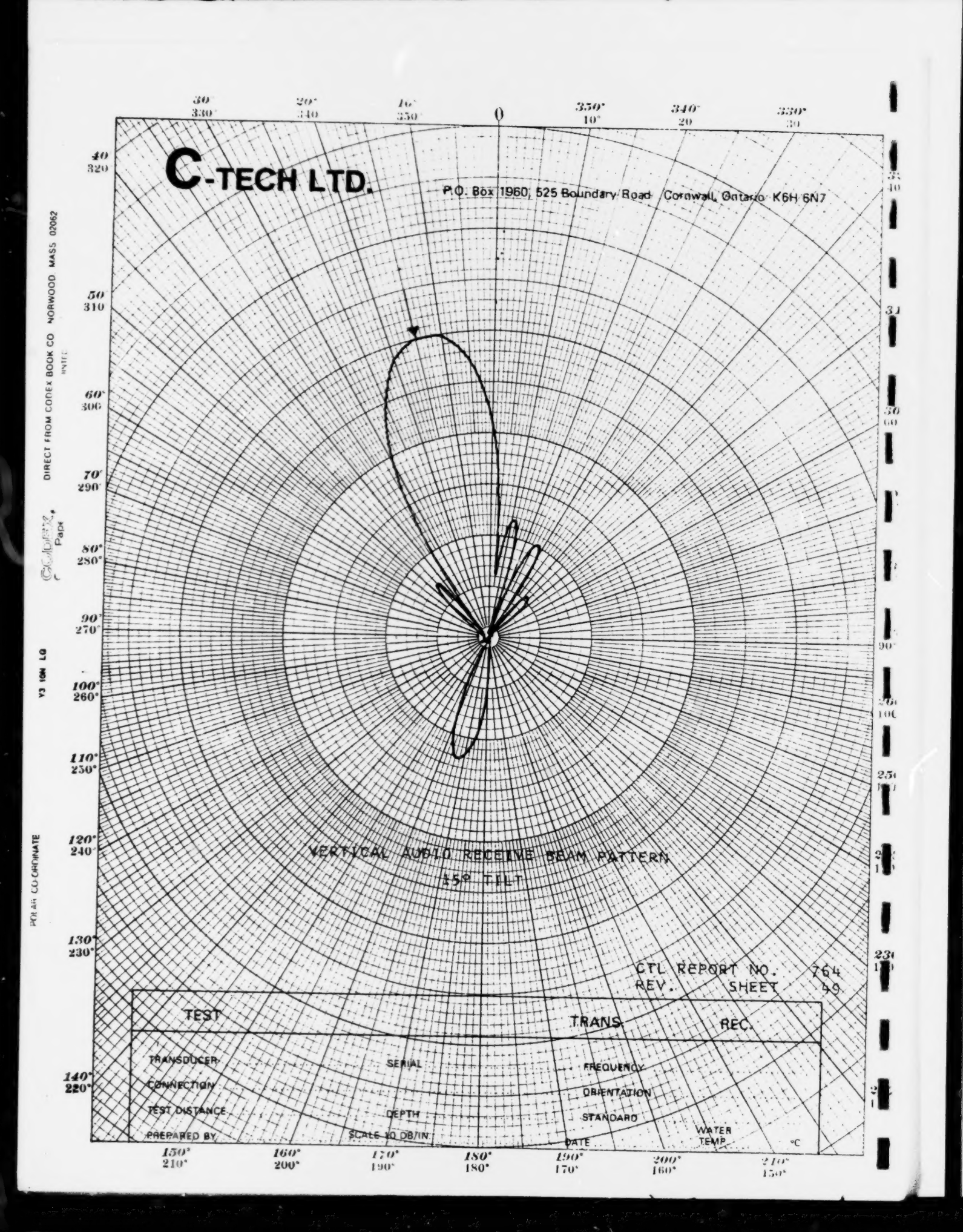
C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL AUDIO RECEIVE BEAM PATTERN
45° TILT
CTL REPORT NO. 764
REV. SHEET 49
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
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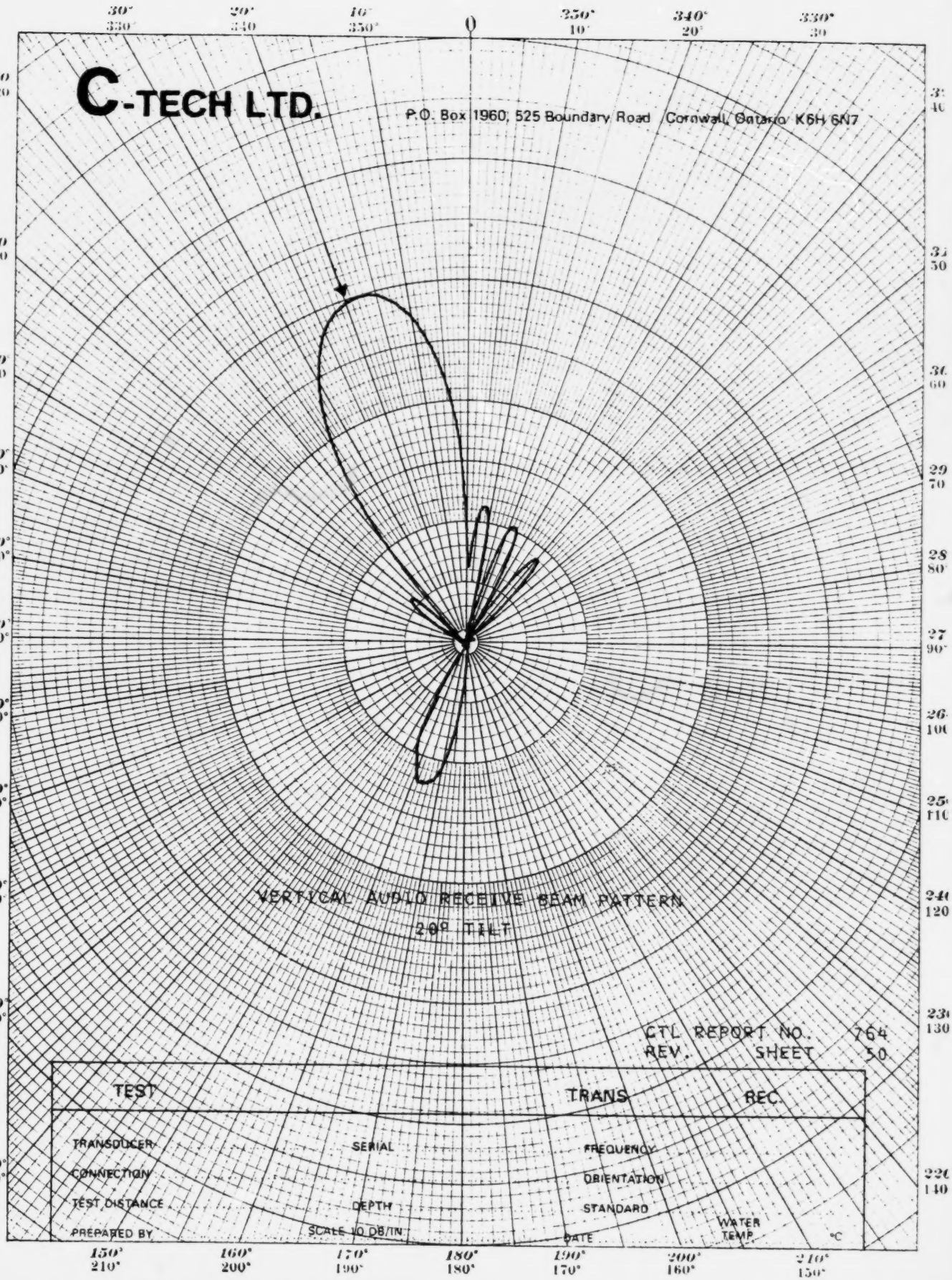
DIRECT FROM CODEX BOOK CO NORWOOD MASS 02062
POLAR CO-ORDINATE
Y3 16N LG


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 6N7
VERTICAL AUDIO RECEIVE BEAM PATTERN
20° TILT
CTL REPORT NO. 764
REV. SHEET 50
TEST
TRANS
REC
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
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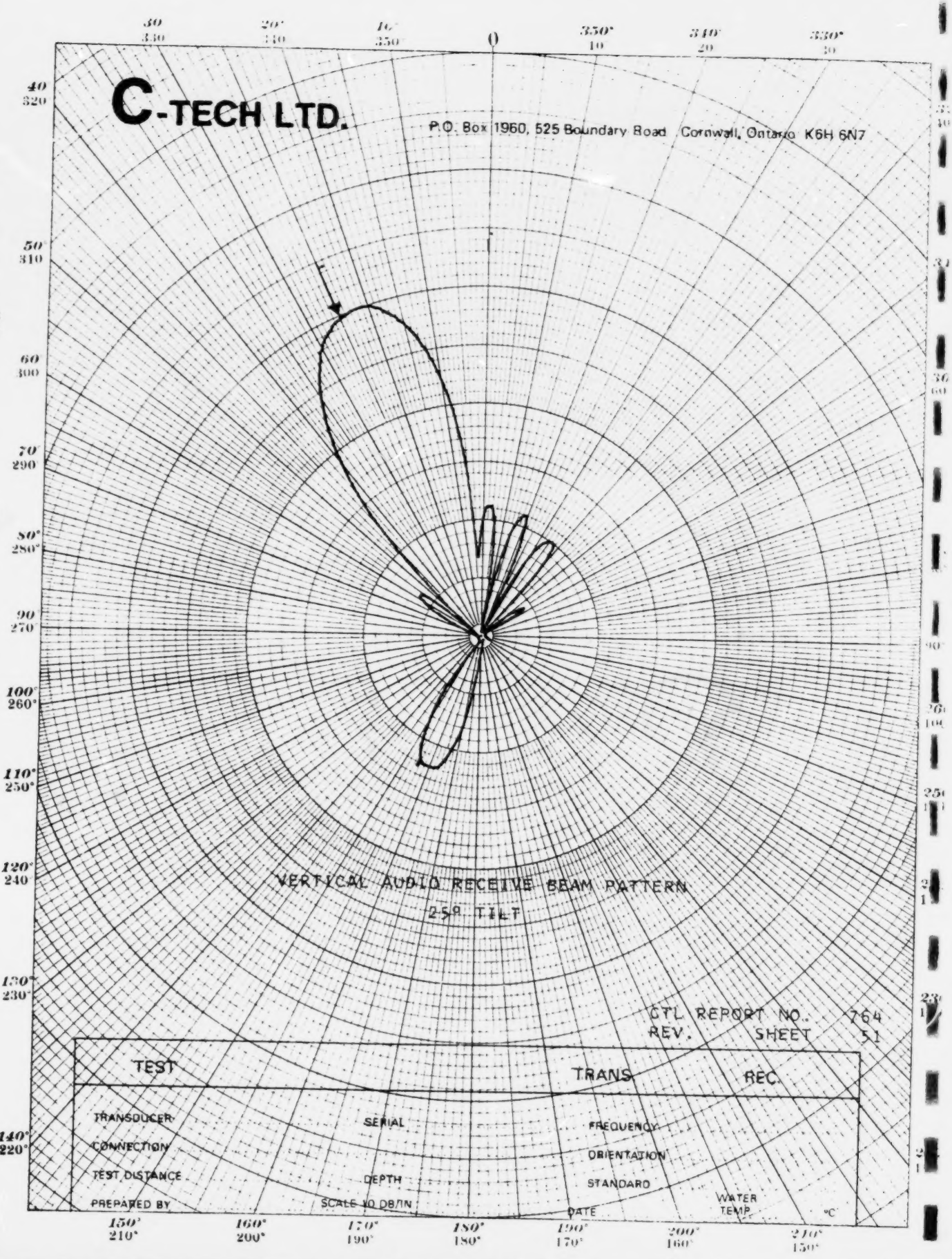
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
330°
340°
350°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VERTICAL AUDIO RECEIVE BEAM PATTERN
25° TILT
CTL REPORT NO. 764
REV. SHEET 51
TEST
TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
°C
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
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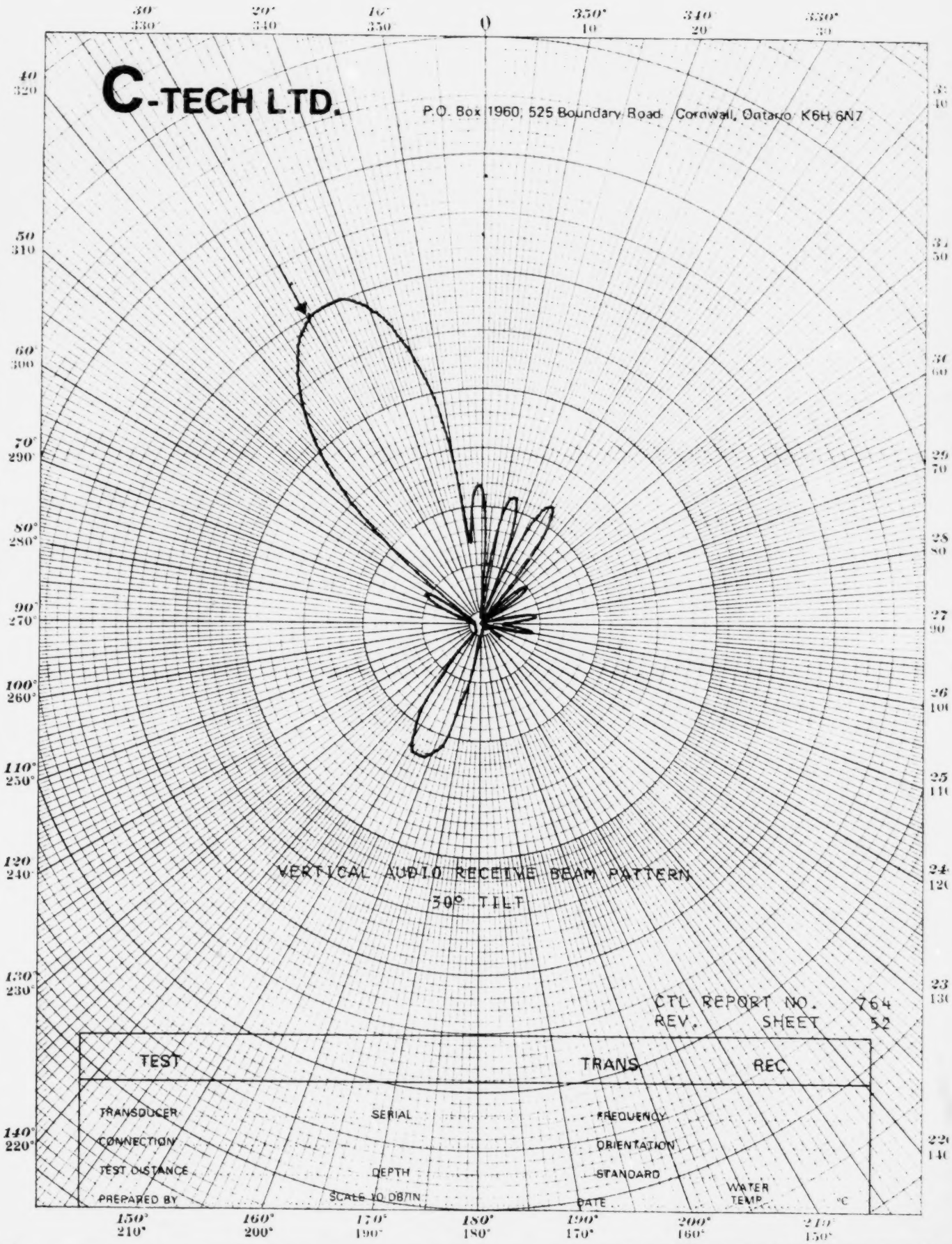
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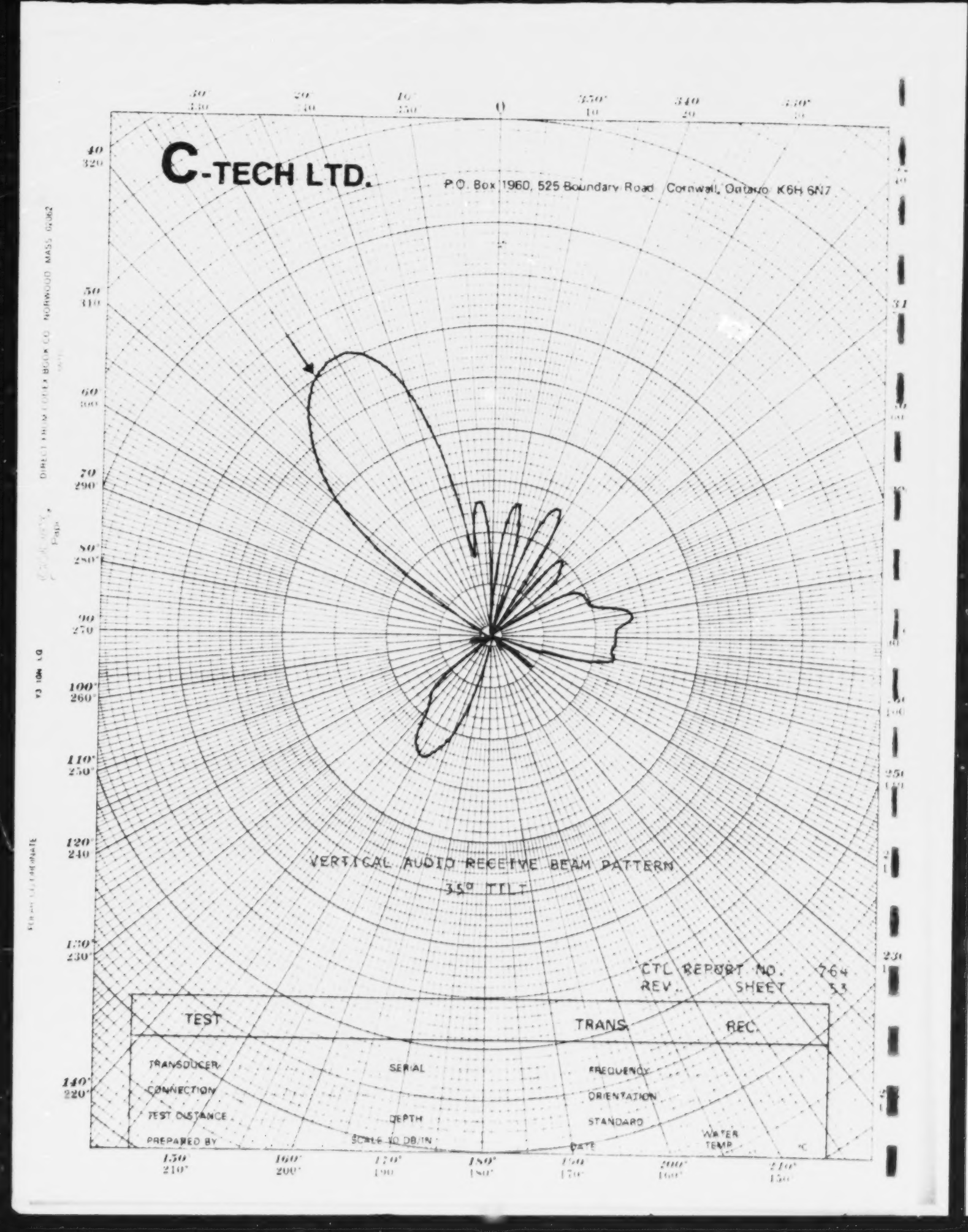
30° TILT
CTL REPORT NO. 764
REV. SHEET 52
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
°C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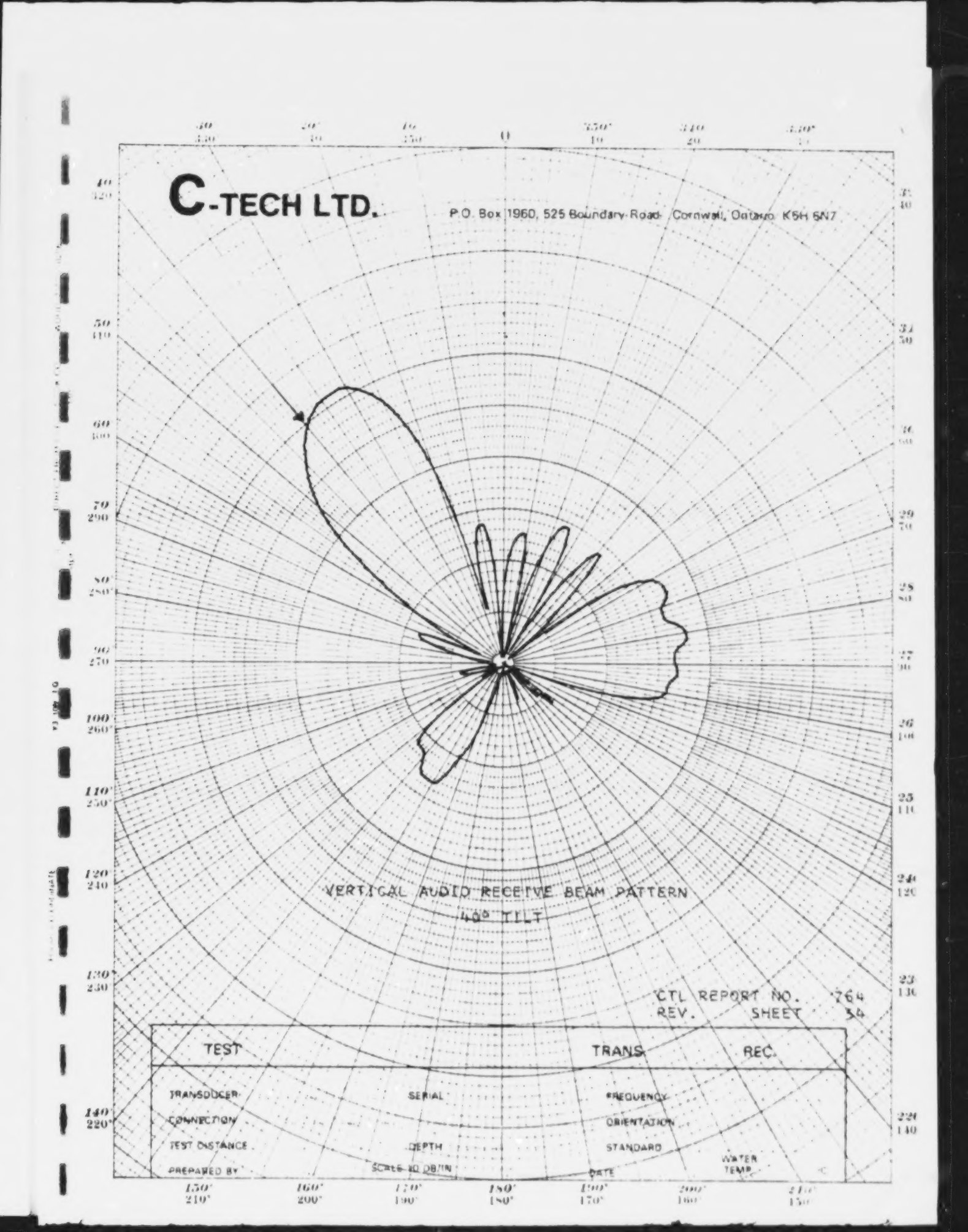
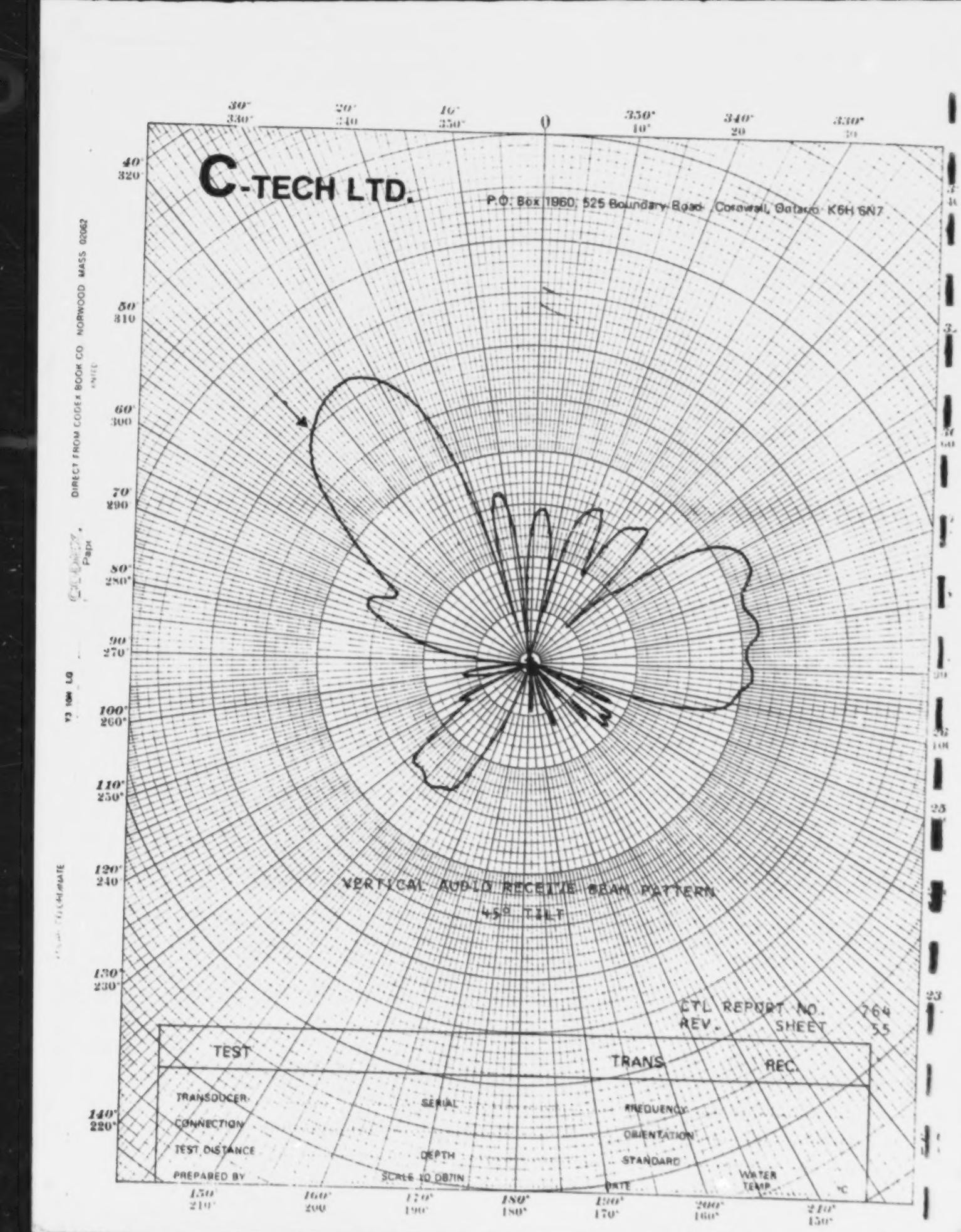
35° TILT
CTL REPORT NO. 764
REV.
SHEET 33
TEST
TRANS.
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP.
°C


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road Cornwall, Ontario K6H 5N7
VERTICAL AUDIO RECEIVE BEAM PATTERN
40° TILT
CTL REPORT NO. 764
REV.
SHEET 34
TEST
TRANS.
REC.
TRANSDUCER
SERIAL
FREQUENCY
CONNECTION
ORIENTATION
TEST DISTANCE
DEPTH
STANDARD
PREPARED BY
SCALE 10 DB/IN
DATE
WATER TEMP.


C-TECH LTD.
P.O. Box 1960, 525 Boundary Road, Cornwall, Ontario K6H 6N7
VERTICAL AUDIO RECEIVE BEAM PATTERN
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CTL REPORT NO. 764
REV.
SHEET 55
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TRANS
REC.
TRANSDUCER
CONNECTION
TEST DISTANCE
PREPARED BY
SERIAL
DEPTH
SCALE 10 DB/IN
FREQUENCY
ORIENTATION
STANDARD
DATE
WATER TEMP
°C
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10° 350°
20° 340°
30° 330°
350° 10°
340° 20°
330° 30°
40° 320°
50° 310°
60° 300°
70° 290°
80° 280°
90° 270°
100° 260°
110° 250°
120° 240°
130° 230°
140° 220°
150° 210°
160° 200°
170° 190°
180°
190° 170°
200° 160°
210° 150°

APPENDIX IV

DIARY OF EVENTS

17-20 July 1984

Installed, secured and tested the data acquisition equipment. Performed preliminary tests on sonar system.

22 July 1984

Left Antwerp - en-route Nanisivick, Baffin Island. Sonar tested using sea floor and ship's wake as targets. Results acceptable.

23 July 1984

Performed data aquistion on bottom echo.

24 July 1984

Aquisition of ship and ambient noise at various speeds and nedings. Ship in ballast, sea state 3. Sonar runs 1 through 6.

25-26 July 1984

En-route Baffin Island.

27 July 1984

First icebergs and bergy bits encountered. Sonar runs 7-10. Small and medium sized targets detected at short range and at slow speed. Plenty of small pieces of ice in water.

First problems encountered with sonar hoist.

28 July

Hoist lowered with manual assistance by C-Tech engineer (as on the succeeding days). Operation takes two hours.

Hugtug is prepared for triplane target tests, eventually postponed because of deteriorating weather conditions.

Runs 8-18 are performed (type Alpha, Bravo, Charlie) around several targets, including bergy bits and small icebergs. Detection ranges in excess of 700 m are observed.

29 July 1984

Echo run (19) is performed with ship at icebreaking draught and at various speeds. Winds of 25 to 30 knots well of 3 to 4 meteres.

Runs Alpha (#20, 21, 22) performed with cubic metre triplane target deployed at various depths from crane #5. Clear echo is obtained.

Runs 23-38 are performed around a number of medium to small icebergs. Detection ranges appear to be determined by the draught of the iceberg. The winds increased to 45 knots during the runs. Detection ranges of up to 700 m are observed. Water depth is approximately 140 m.

30 July 1984

Vessel in the area of Disko Island, and surrounded by icebergs.

Runs 29-45 are performed (with detections at variable ranges) around icebergs of dimensions varying from the large iceberg (25 million tonnes) to the small growlers (25 tonnes). Detection vary from 200 m to the maximum sonar range of 2000 m.

Working conditions ideal: water is moderately deep (approximately 40 m), sea is calm, there are many icebergs in a small area. This should result in good target strength estimates. Detection appears to be limited by the icberg draught in relation to the sound speed profile. With increasing range, the echo disappears quite abruptly.

31 July

Run 46 is performed with the reference target suspended from the Hugtug. After some difficulties (manoeuvres, shallow water), good echoes are obtained. It is noted that the bearing scale of the C-Tech sonar is off by about 10 degrees to starboard - faulty installation suspected.

ECHO type run 47, noise acquisition at 4 knots with bubblers in operation to check for any excessive noise increase. No such effect is noticed.

The recovery of the C-Tech transducer, which on the previous days occurred almost without problems, takes about five times longer than normal (i.e., 2.5 minutes rather than 42 seconds).

01 August 1984

Attempting to perform a noise measurement as the ship is going through pack ice. This is frustrated by the unreliability of the transducer hoist system, and the fog. Master judges that, under the circumstances, it would be unwise to lower the transducer. This is the only planned measurement which could not be performed during the entire trials.

02 August 1984

Arrival in Nanisivik.

C-Tech and Canadian Astronautics personnel and data acquisition equipment return to Ontario by air.

APPENDIX V

ICEBERG DATA SUMMARY

APPENDIX V

Data Summary

Run No.	Run Type	Iceberg No.
8	Alpha	1
9	Alpha Reject	1
10	Bravo Reject	1
11	Alpha/Drift	2
12	Alpha	2
13	Bravo	2
14	Alpha/Charlie	3
15	Alpha/Charlie	3
16	Bravo	3
17	Alpha	4
18	Alpha	4
23	Alpha	5
24	Bravo (CCW)	5
25	Alpha Drift	6
26	Alpha	6
27	Bravo (CCW)	6
28	Alpha	7
29	Alpha	8
30	Bravo (CCW)	8
33	Alpha	9
34	Alpha	9
38	Alpha	11
39	Charlie/Bravo	11
40	Charlie	12
41	Charlie Reject	12
42	Alpha	13
43	Charlie	14

DATA SUMMARY ICEBERG NO. 1

Sea State 0 Wind Speed Calm

Water Depth Not Recorded

Date	Run No.	Run Type	Comments
27 July	8	Alpha/Charlie	14 out of 15 readings used
27 July	9	Alpha	all 7 readings rejected
28 July	10	Bravo	all 40 readings rejected due to insufficient control parameters

ICEBERG DESCRIPTION

Height above waterline	12 m
Length at waterline	35 m
Estimated Draught	40 m
Iceberg Classification	Small

TARGET STRENGTH MEASUREMENTS

Number of Estimates 14

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	-10.67	- 6.66
Standard Deviation dB	4.19	2.43
Median	- 9.78	- 6.18
10th Percentile	- 6.27	- 4.06
90th Percentile	-18.36	-11.85

ICEBERG #01

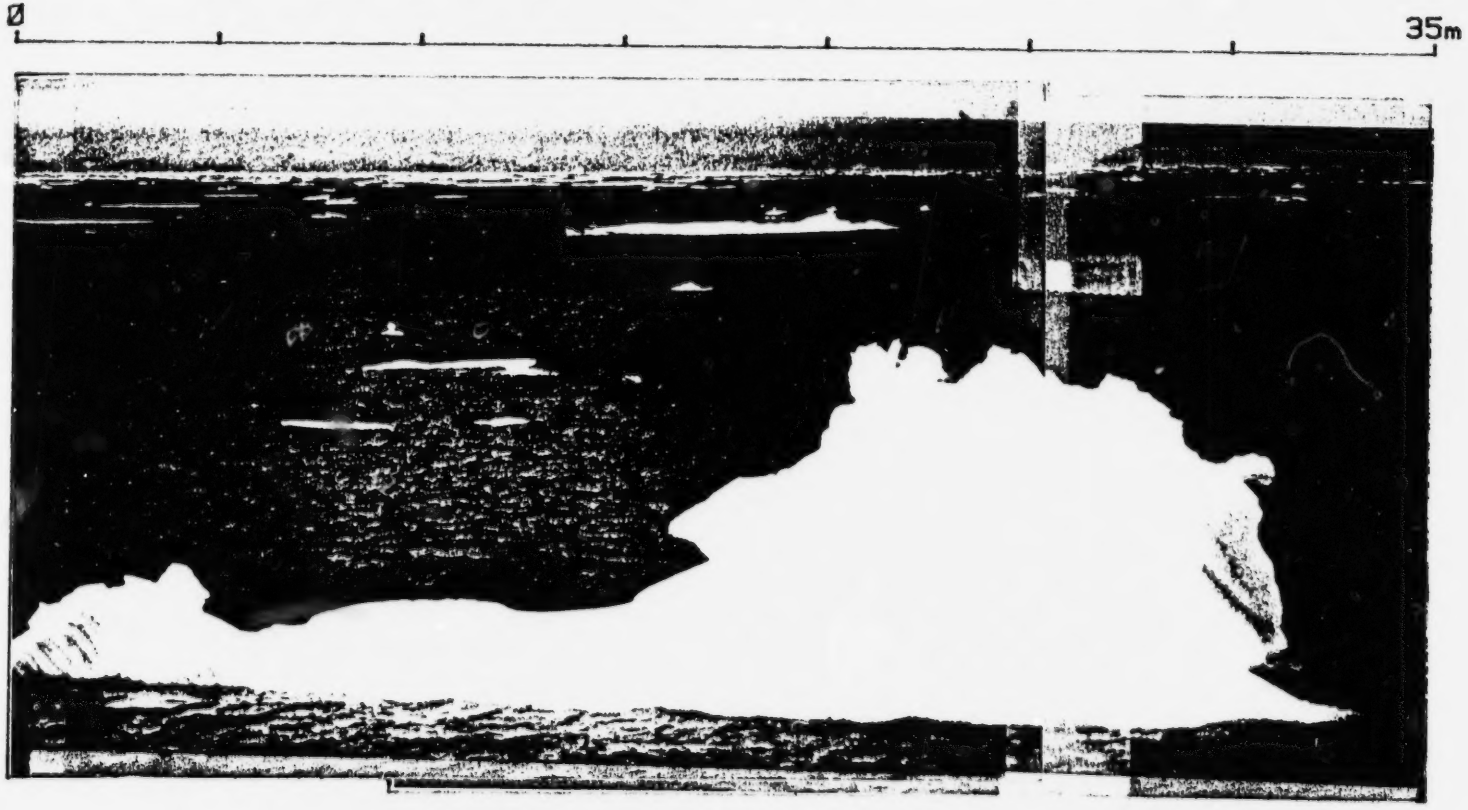


PLATE A1

RUN #8 -> ALPHA/CHARLIE

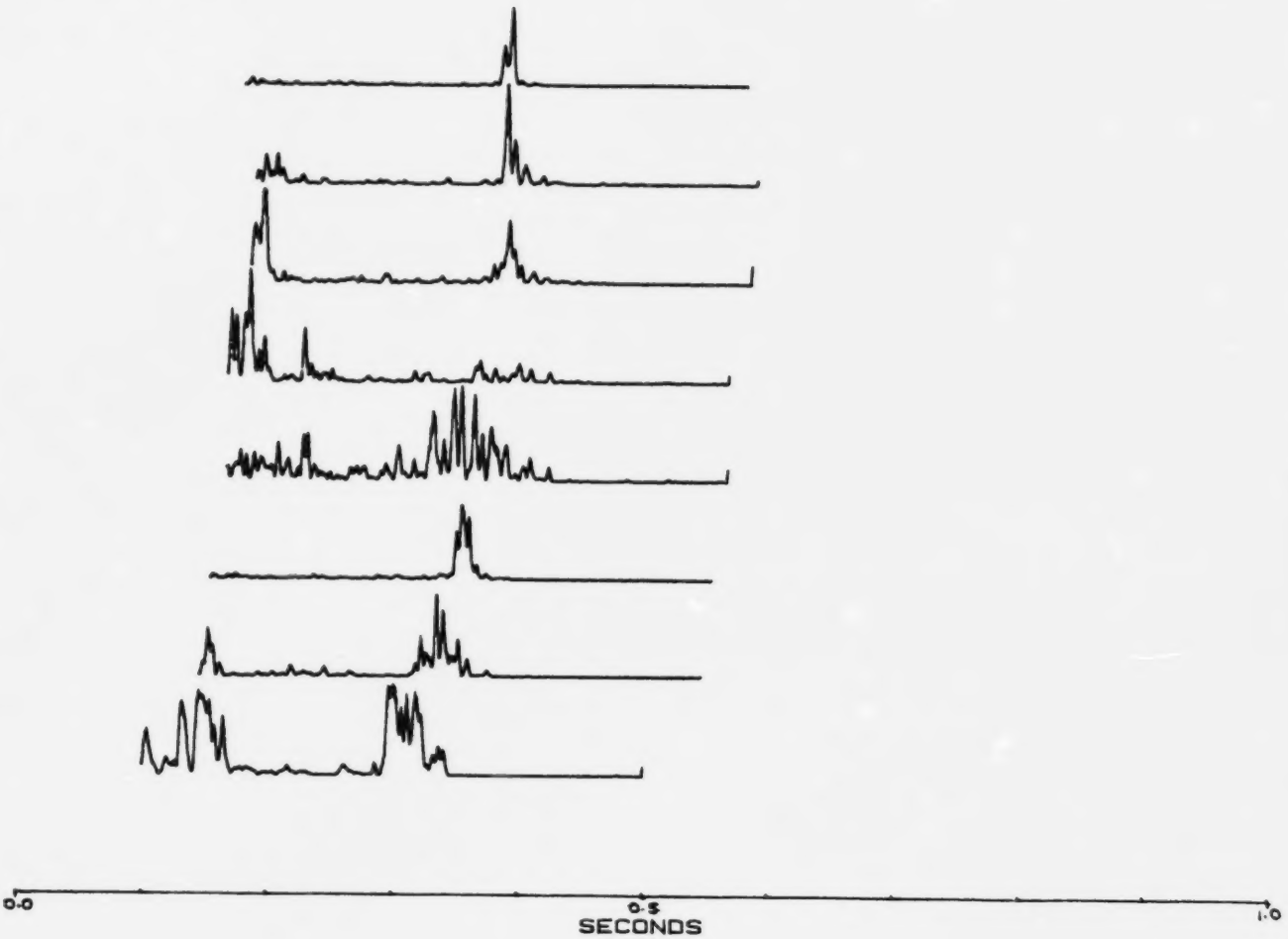
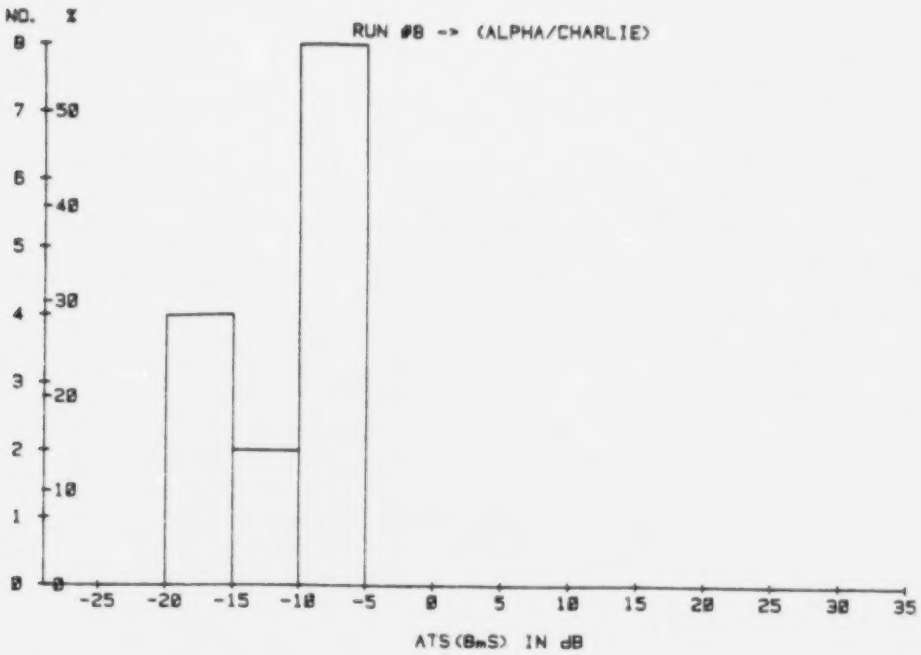


Figure A1 Iceberg #1, Run #8, Representative Echo Power Envelope



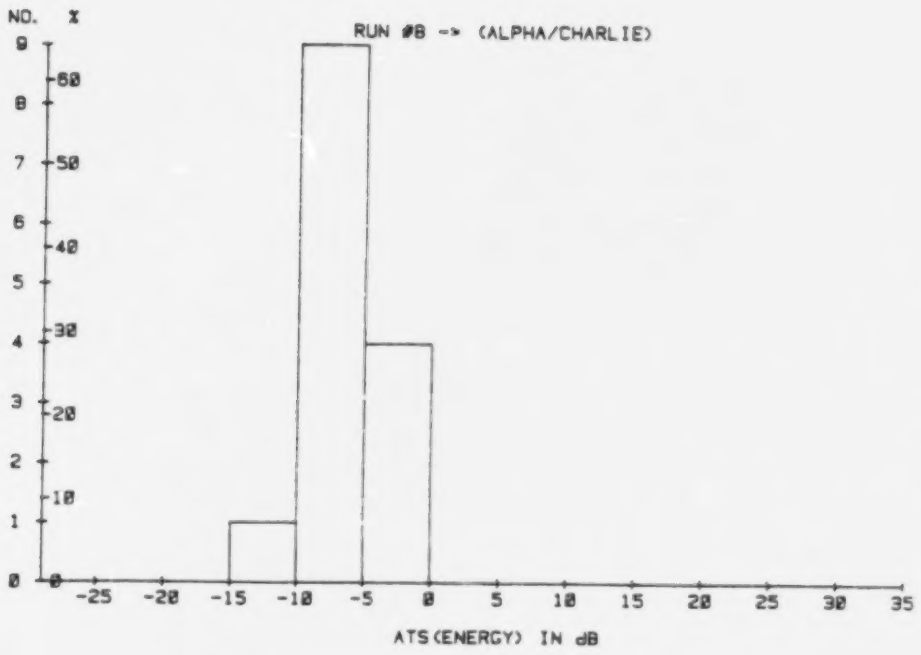


Figure A2 Iceberg #1, Run #8, Target Strength Statistics

DATA SUMMARY ICEBERG NO. 2

Sea State 1 Wind Speed 15 knots

Water Depth not recorded

Date	Run No.	Run Type	Comments
28 July	11	Alpha/Drift	15 out of 40 readings used
28 July	12	Alpha/Drift	39 out of 45 used (questionable settings)
28 July	13	Bravo	12 out of 24 used; iceberg cracked during run.

ICEBERG DESCRIPTION

Height above waterline	32 m
Length at waterline	144 m
Estimated Draught	90 m
Iceberg Classification	Medium

TARGET STRENGTH MEASUREMENTS

Number of Estimates 66

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB		21.39
Standard Deviation dB		5.86
Median		20.42
10th Percentile		28.65
90th Percentile		14.43

ICEBERG #02

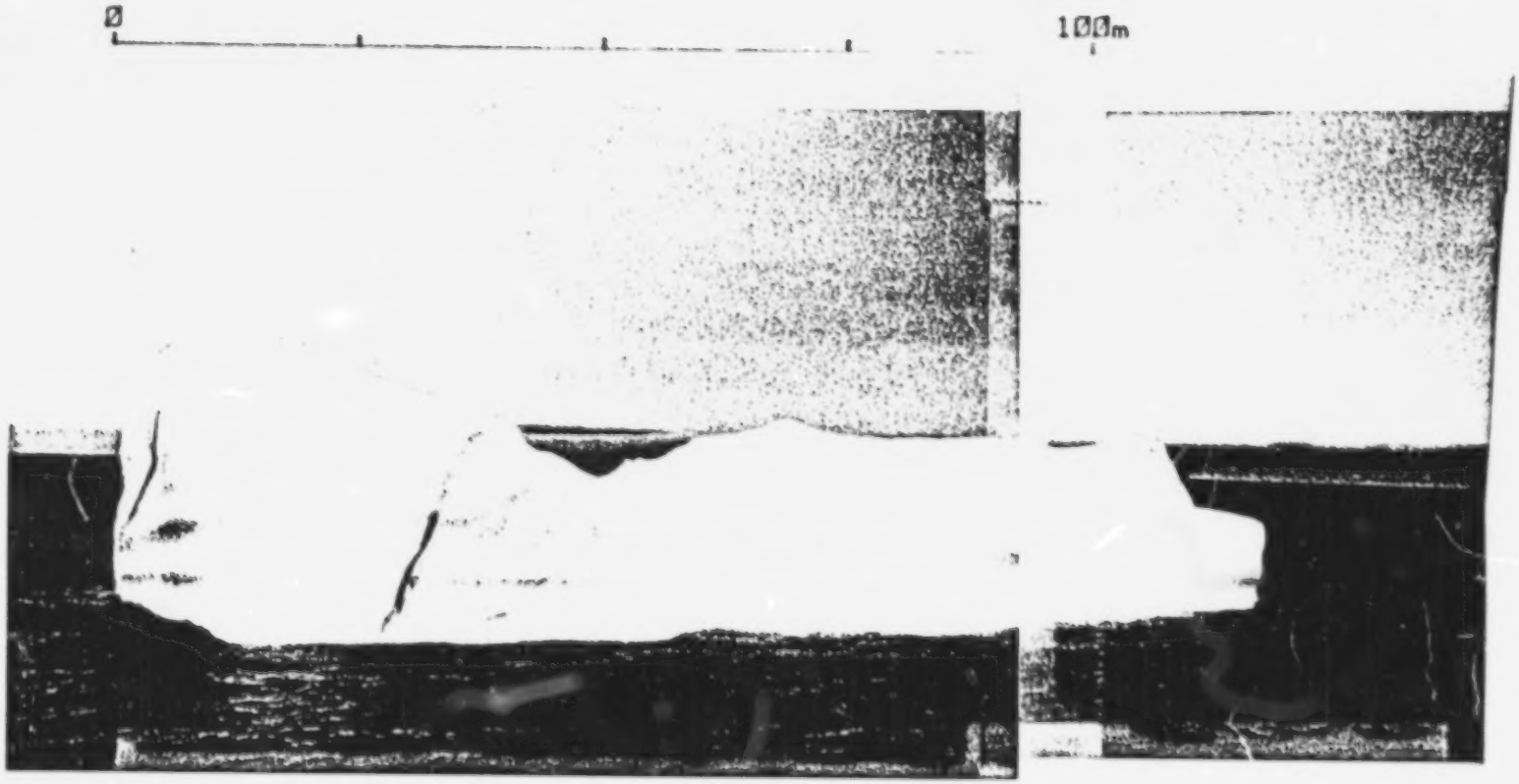


PLATE A2

RUN #11 -> ALPHA DRIFT <-

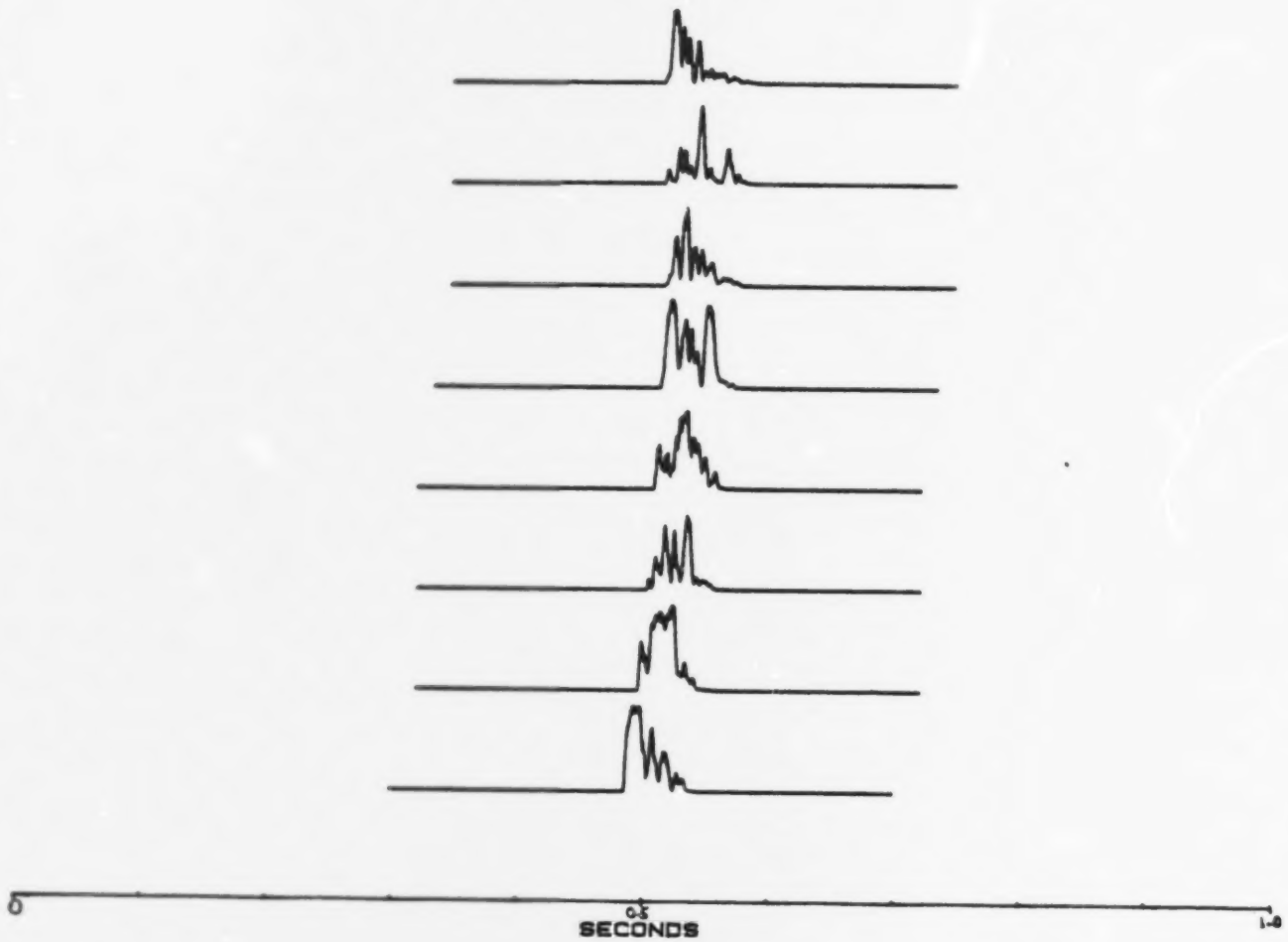


Figure A 3 Iceberg #2, Run #11, Representative Echo Power Envelope

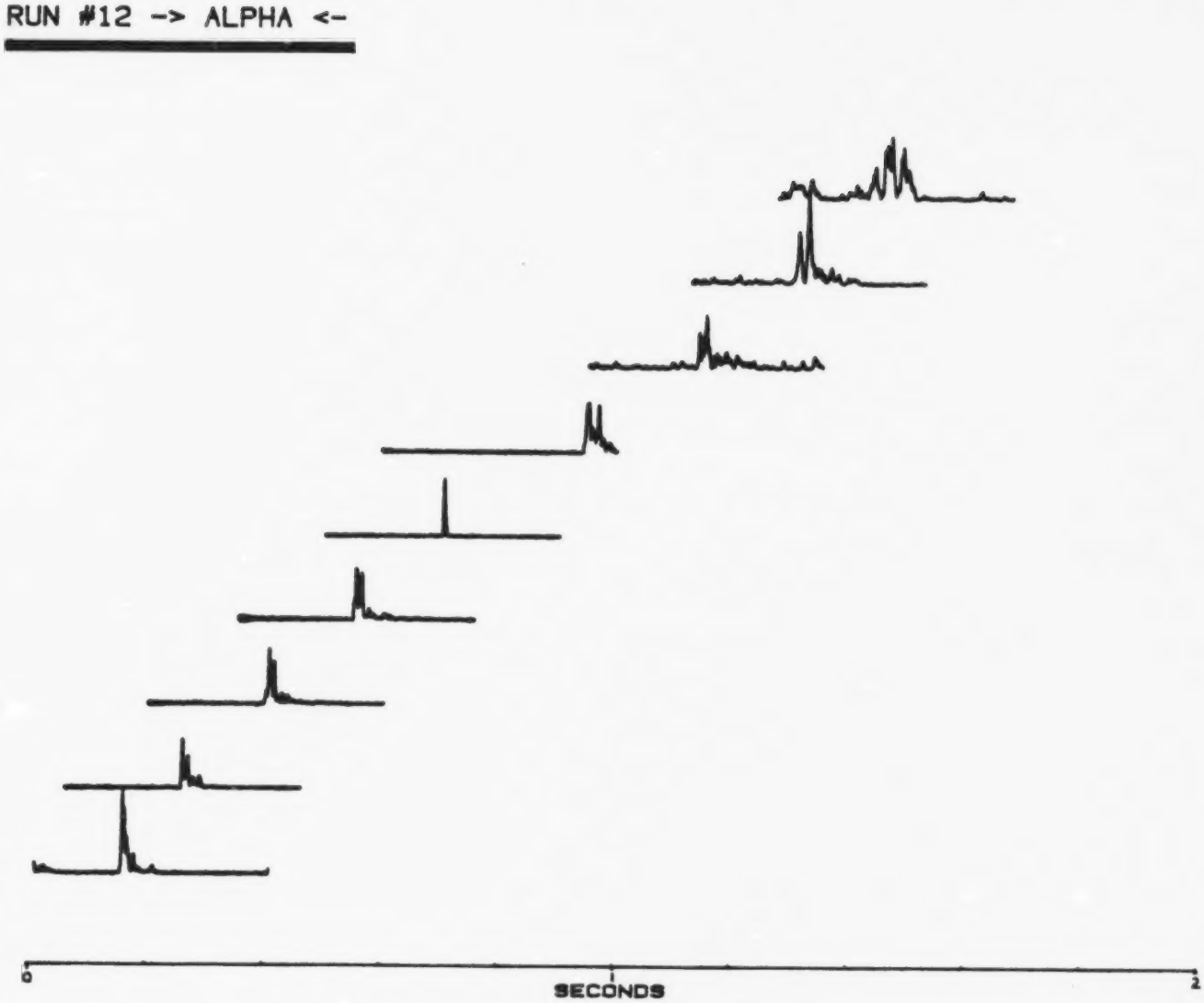


Figure A4 Iceberg #2, Run #12, Representative Echo Power Envelope

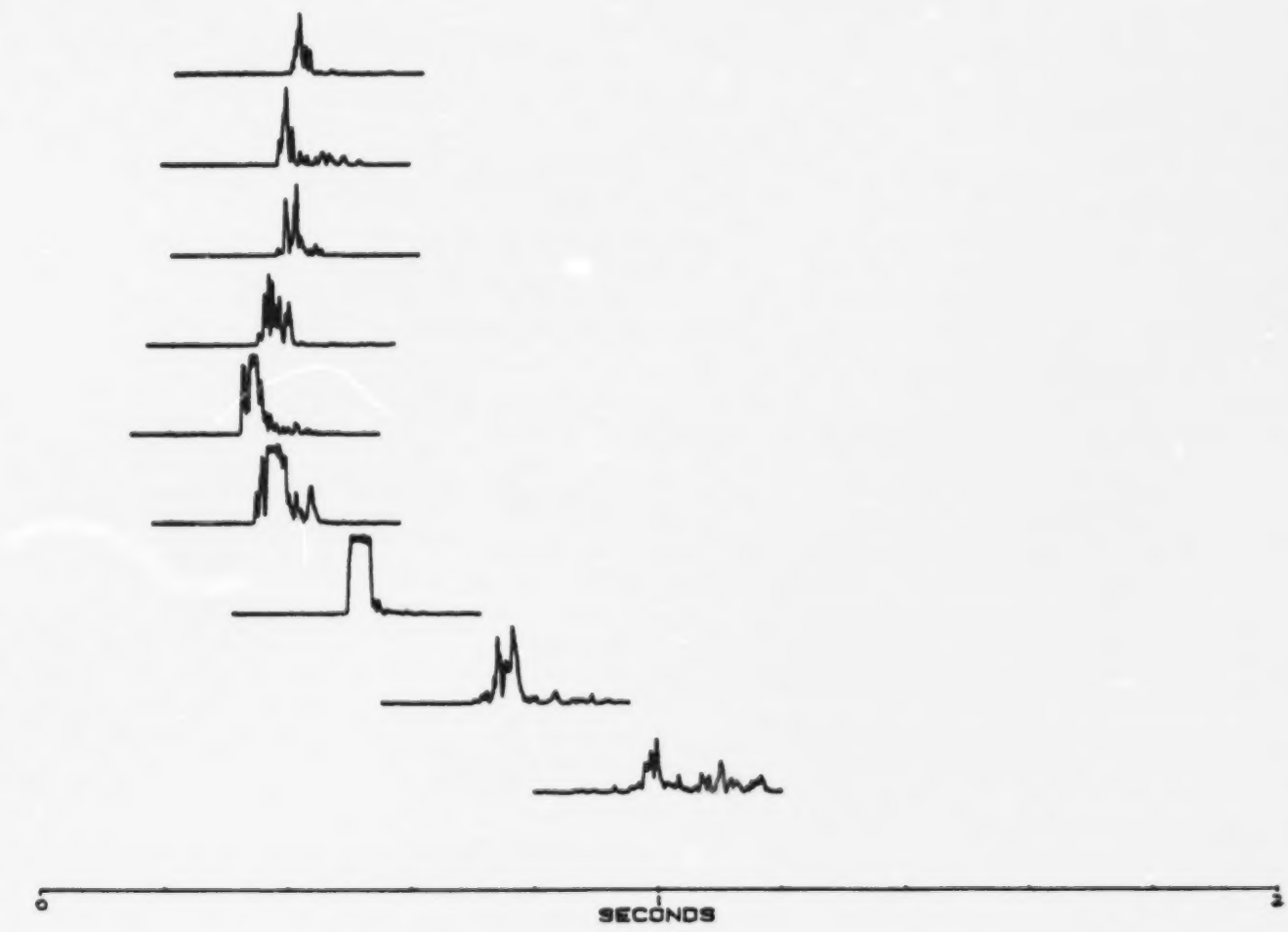
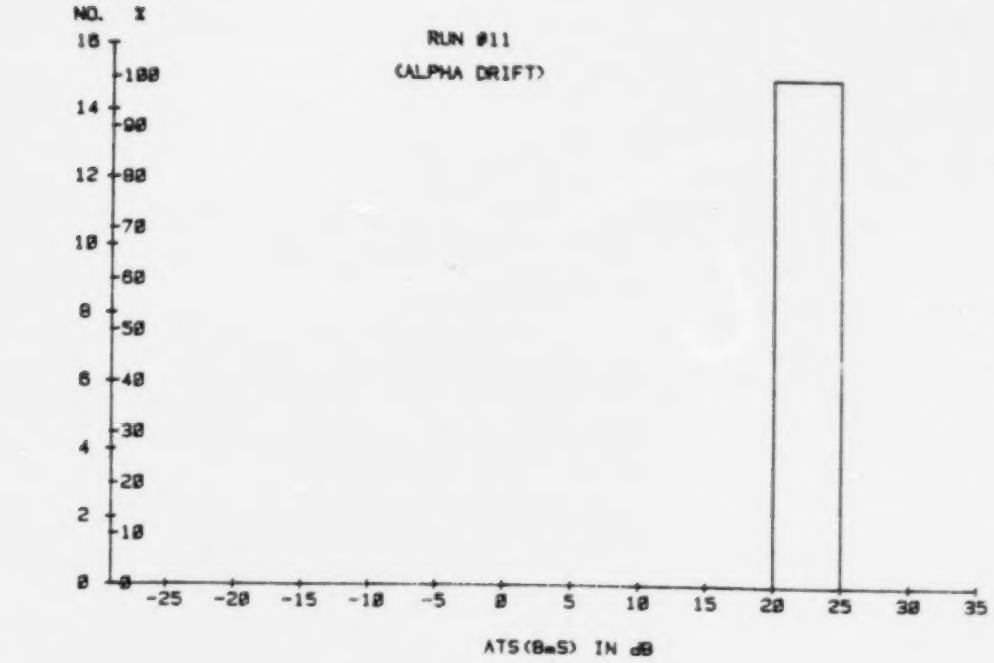


Figure A5 Iceberg #2, Run #13, Representative Echo Power Envelope



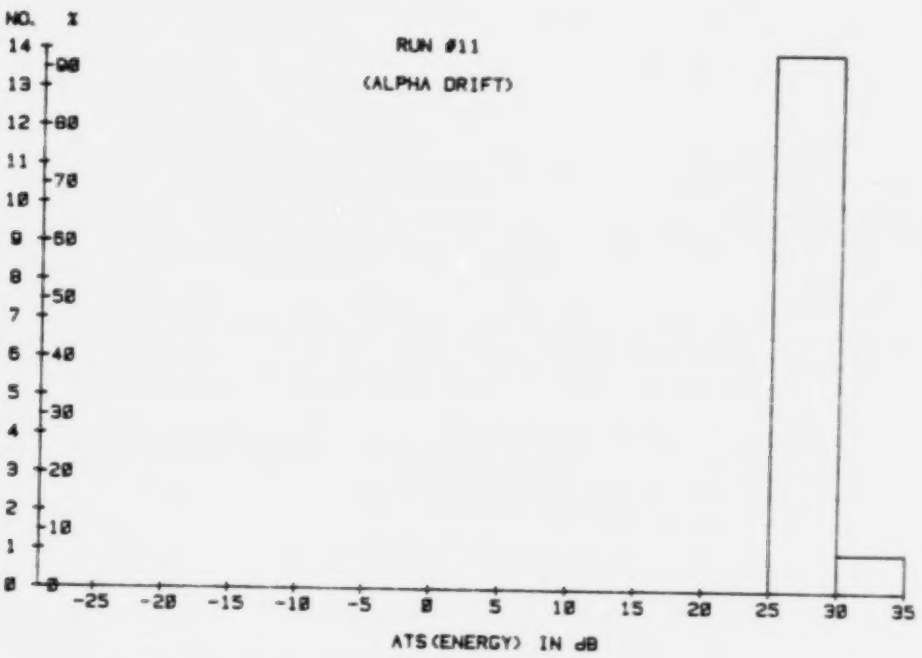
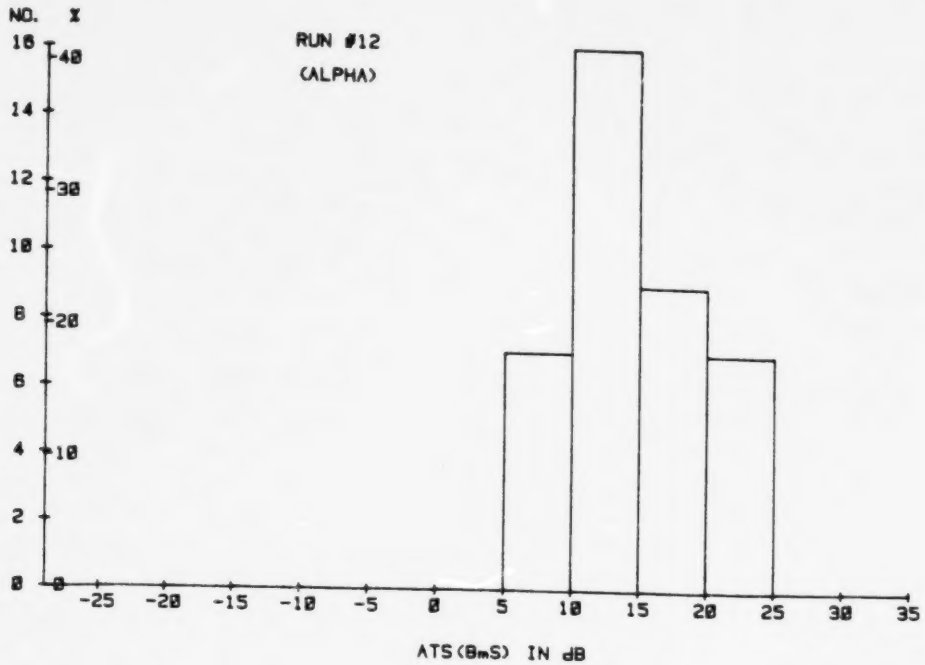


Figure A6 Iceberg #2, Run #11, Target Strength Statistics



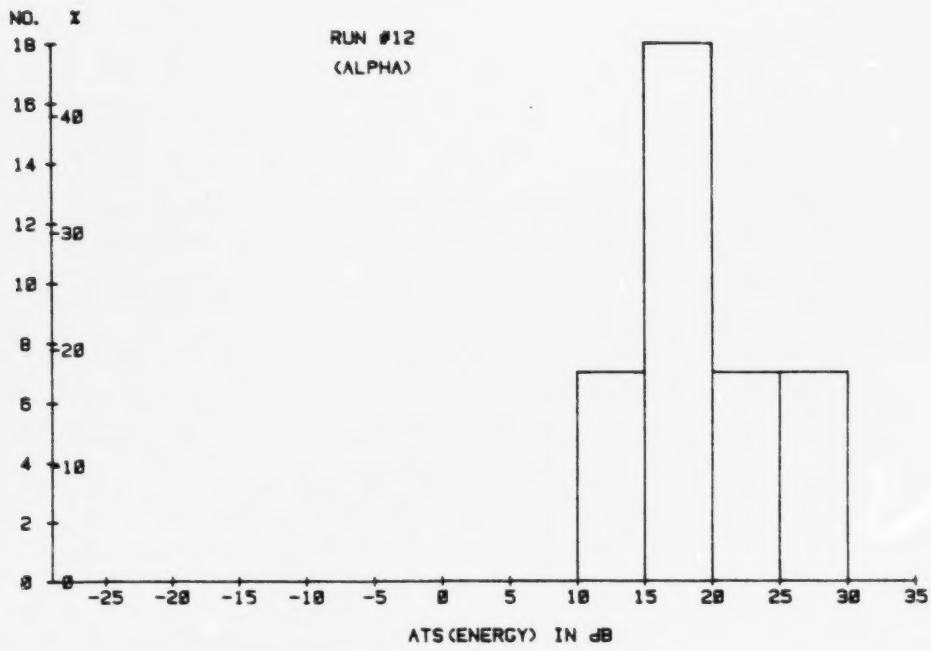
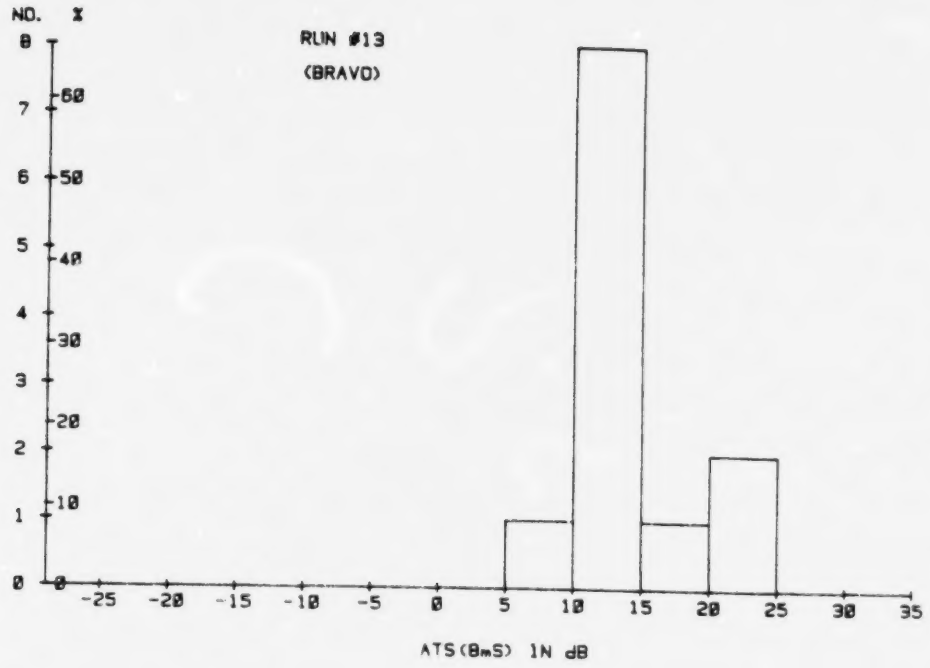


Figure A7 Iceberg #2, Run #11, Target Strength Statistics



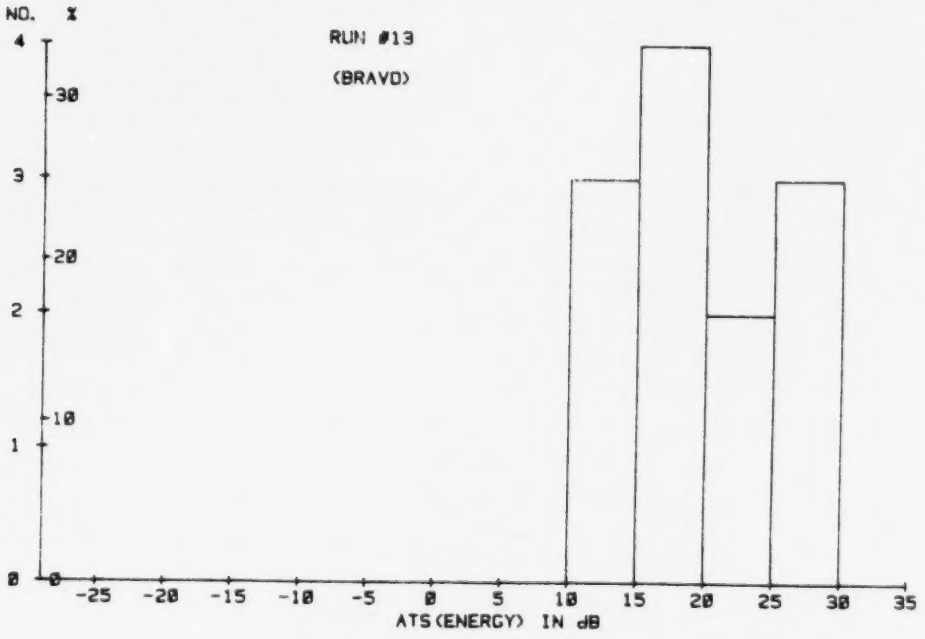
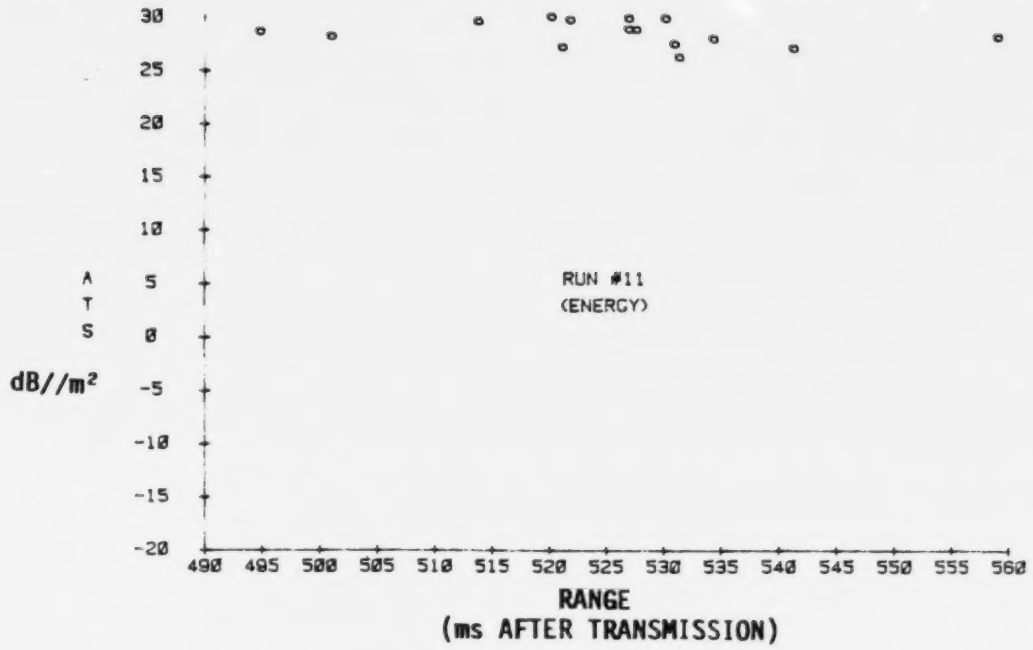


Figure A8 Iceberg #2, Run #13, Target Strength Statistics



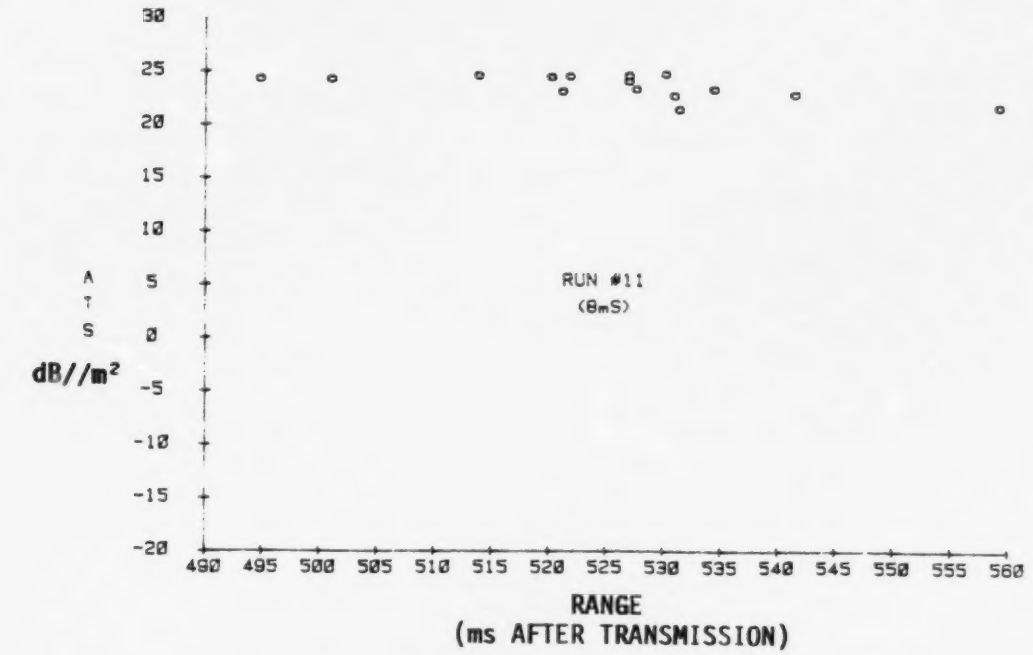
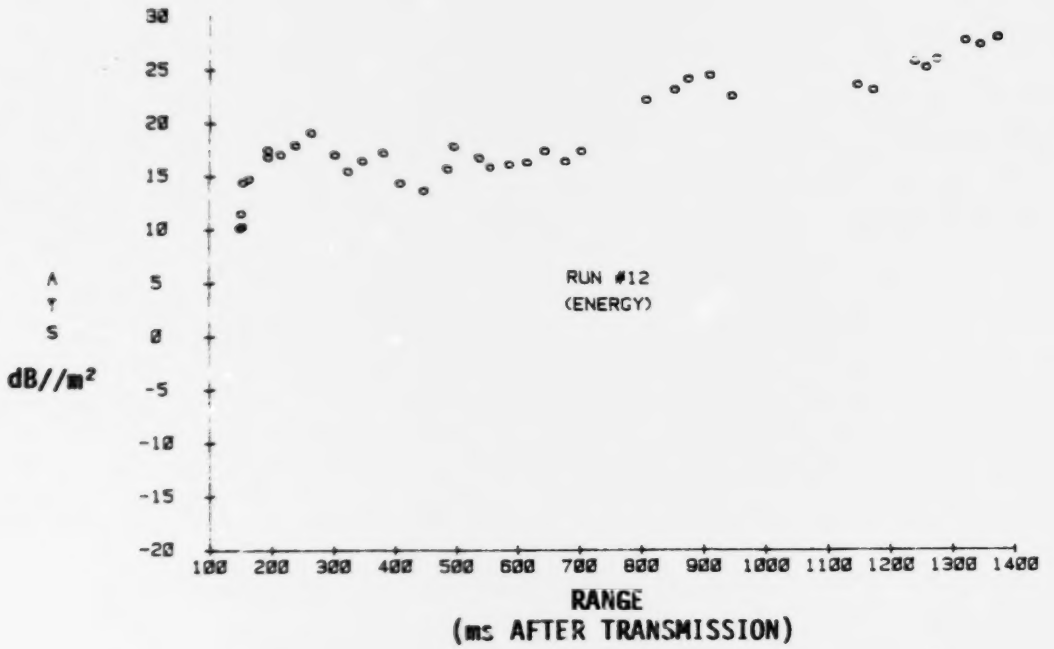


Figure A9 Iceberg #2, Run #11, Acoustic Target Strength



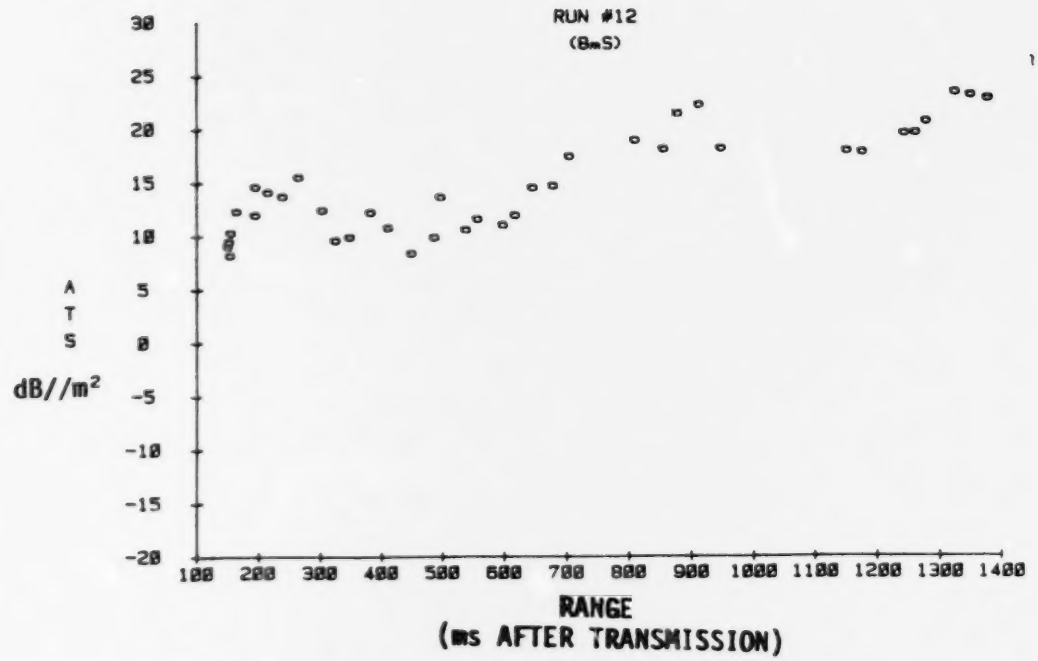


Figure A10 Iceberg #2, Run #12, Acoustic Target Strength

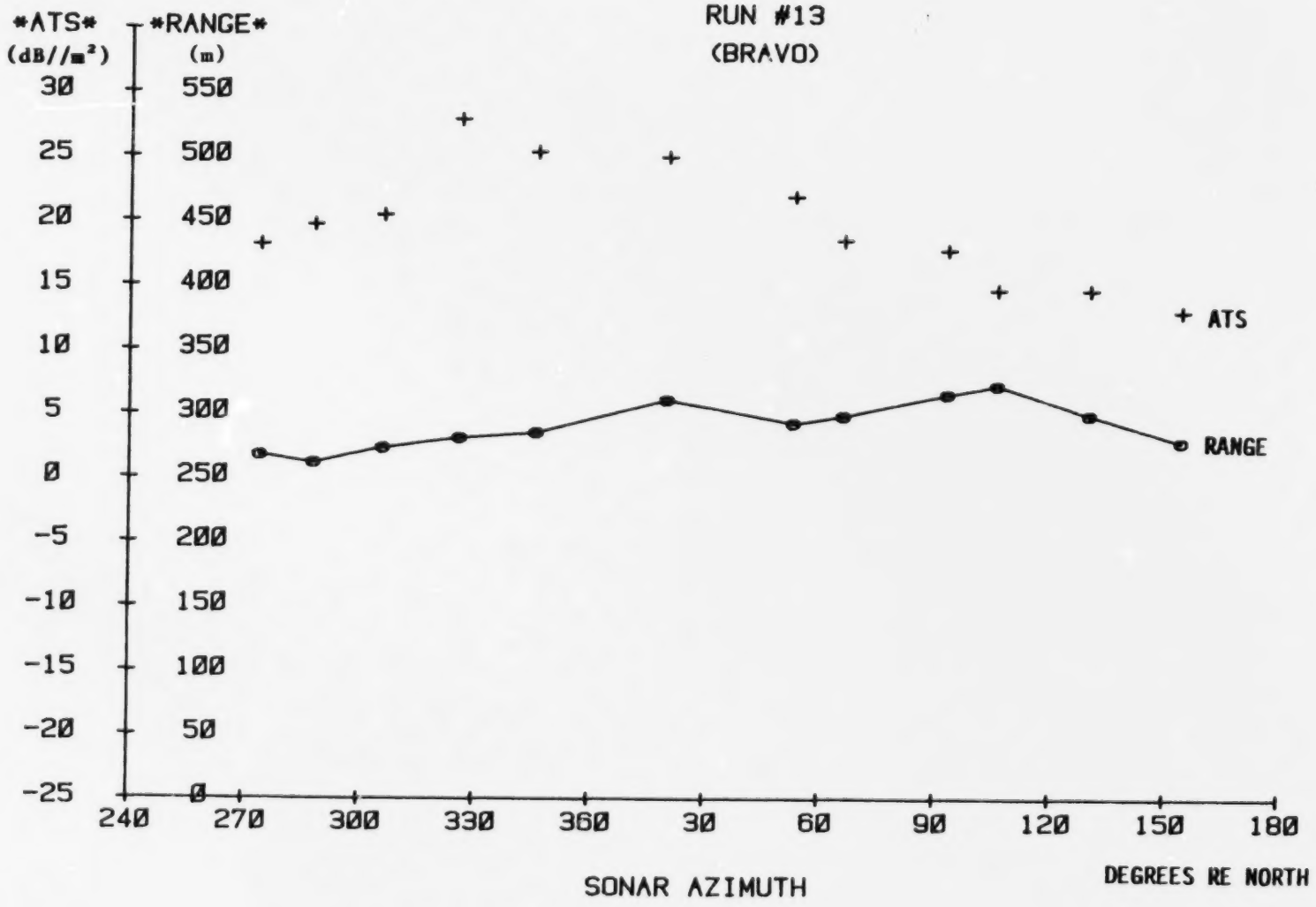


Figure A11 Iceberg #2, Run #12, Acoustic Target Strength and Range vs Sonar Azimuth

DATA SUMMARY ICEBERG NO. 3

Sea State 1

Wind Speed Not recorded

Water Depth Not recorded

Date	Run No.	Run Type	Comments
28 July	14	Alpha/Charlie	5 out of 15 readings used
28 July	15	Alpha/Charlie	6 out of 15 readings used
28 July	16	Bravo	52 of 55 readings used; good detection out to 600 m

ICEBERG DESCRIPTION

Height above waterline	40 m
Length at waterline	112 m
Estimated Draught	120 m
Iceberg Classification	Medium picturesque berg

TARGET STRENGTH MEASUREMENTS

Number of Estimates 63

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	14.19	17.97
Standard Deviation dB	4.77	4.82
Median	14.24	18.58
10th Percentile	20.34	23.88
90th Percentile	8.66	12.94

ICEBERG #03

0 100m

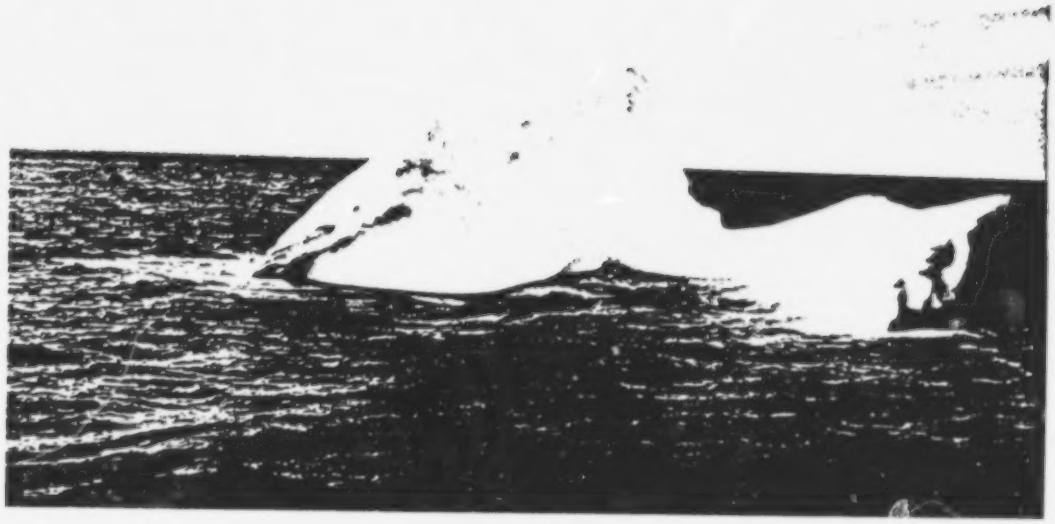


PLATE A3

RUN #14 -> ALPHA CHARLIE <-

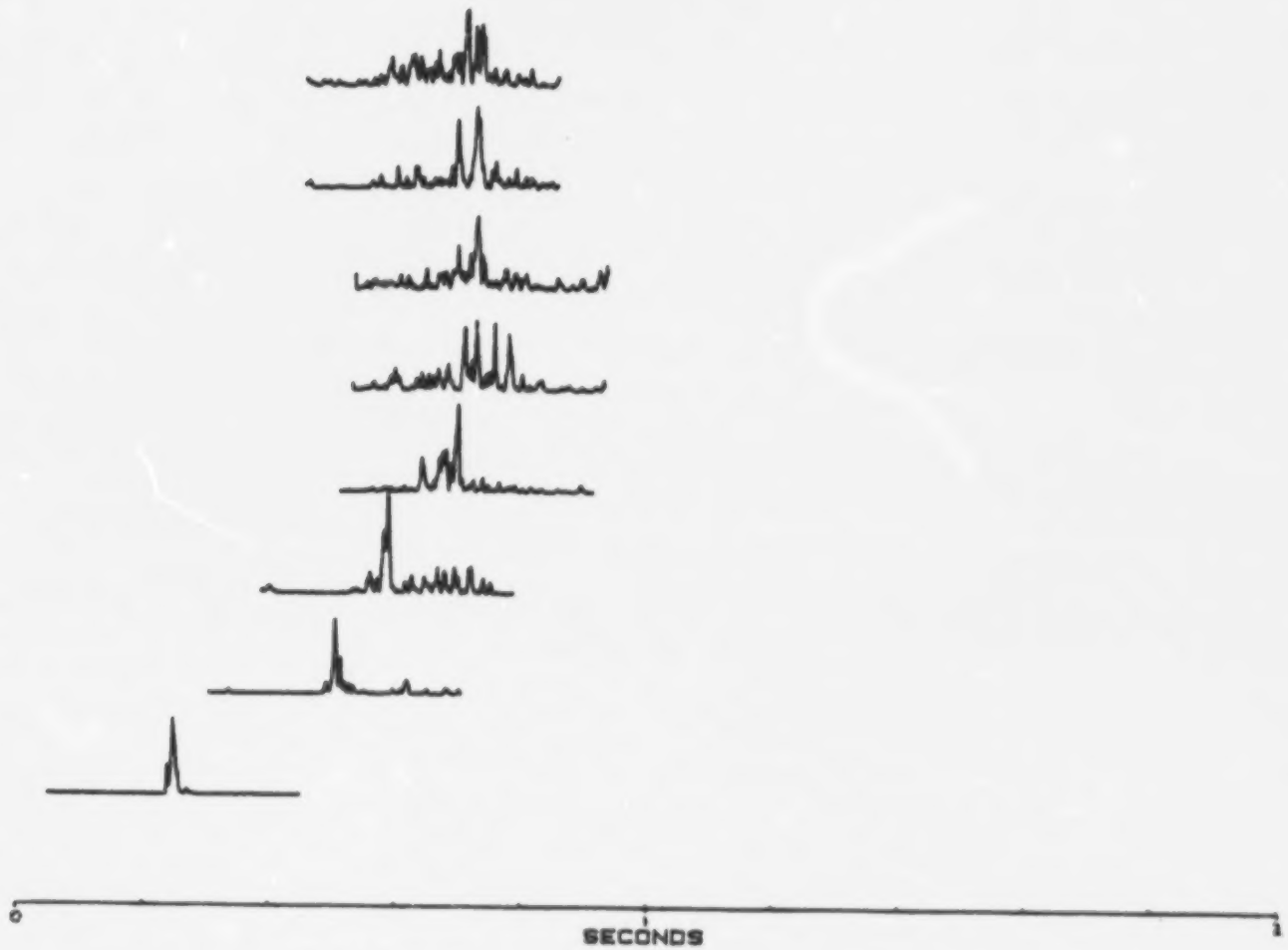


Figure A12 Iceberg #3, Run #14, Representative Echo Power Envelope

RUN #15 -> ALPHA CHARLIE <-

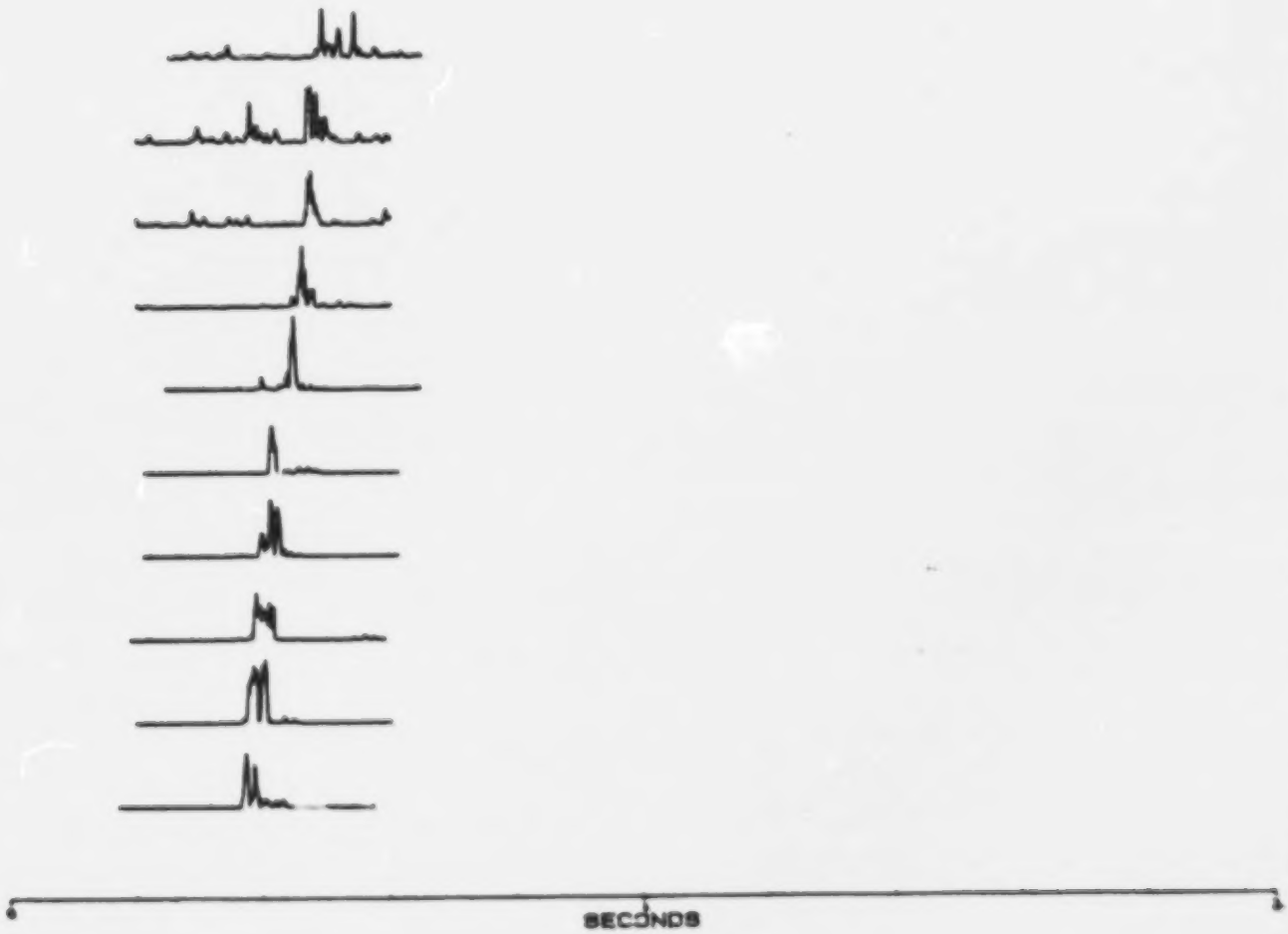


Figure A13 Iceberg #3, Run #15, Representative Echo Power Envelope

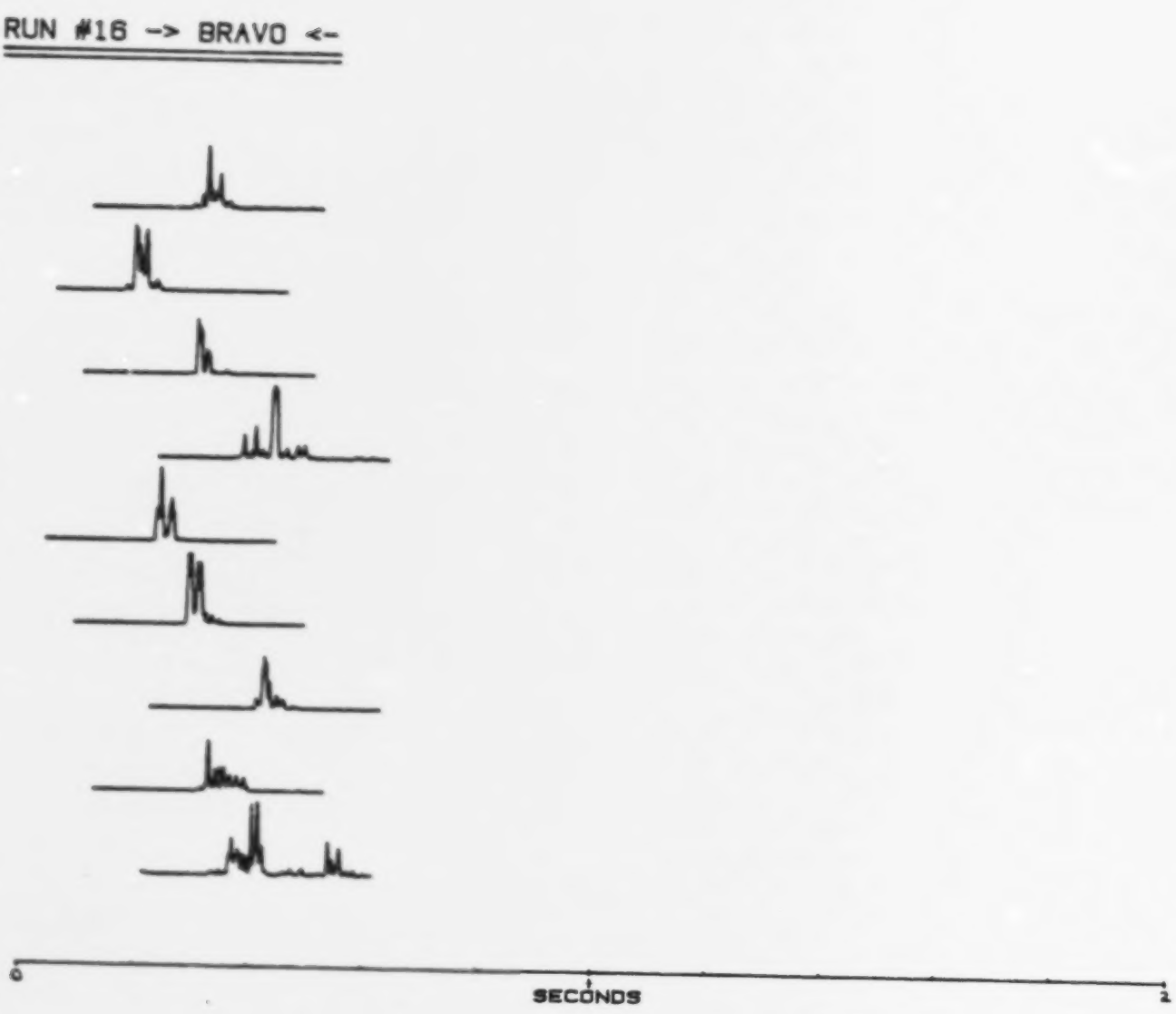
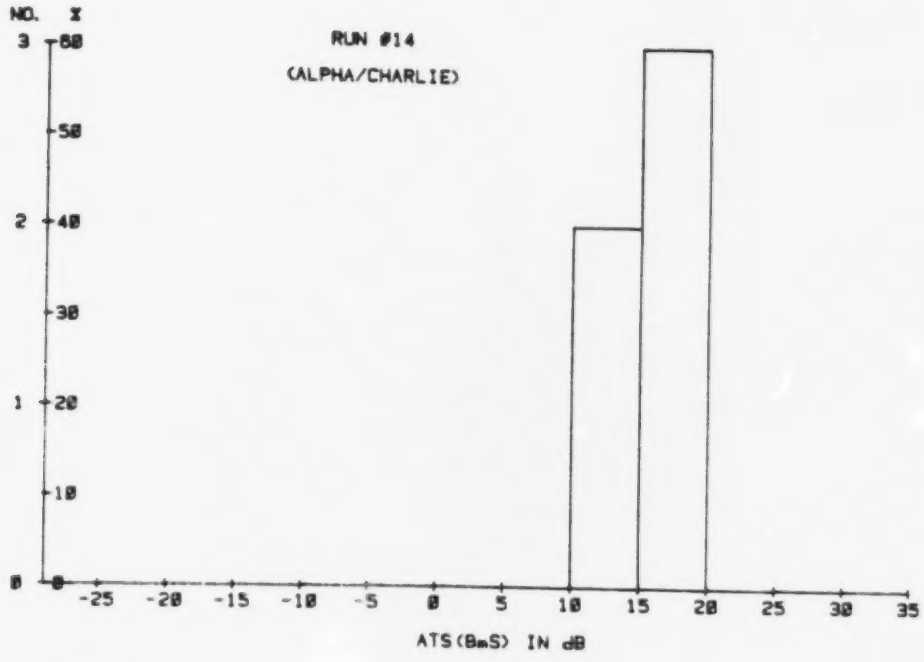


Figure A14 Iceberg #3, Run #16, Representative Echo Power Envelope



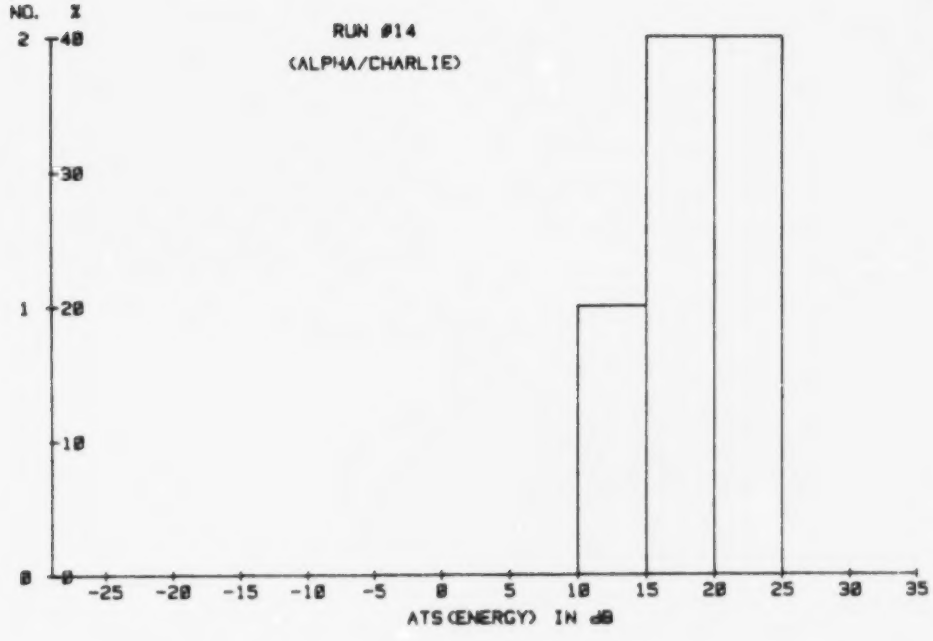
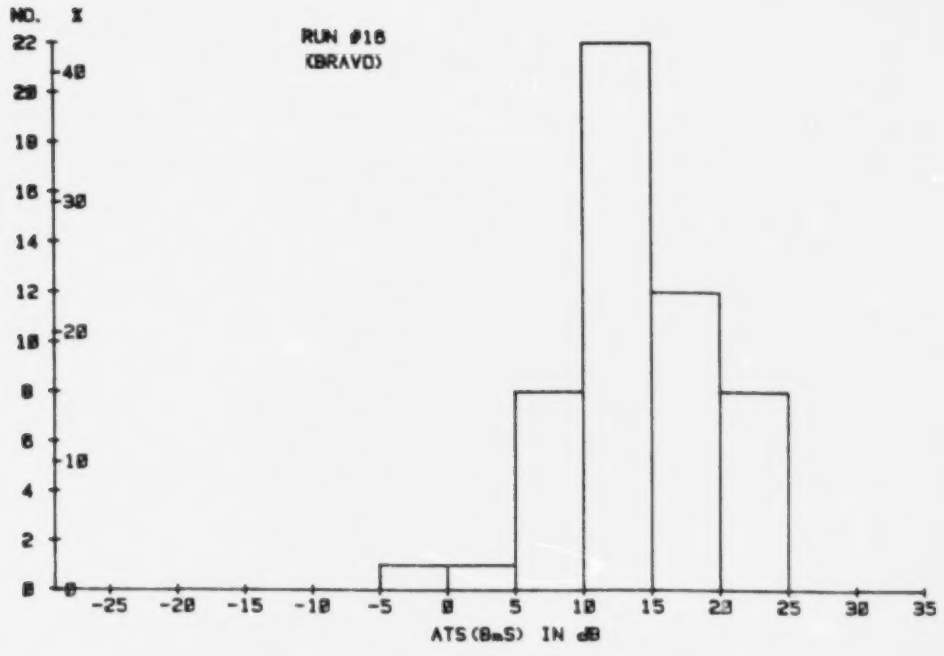


Figure A15 Iceberg #3, Run #14, Target Strength Statistics



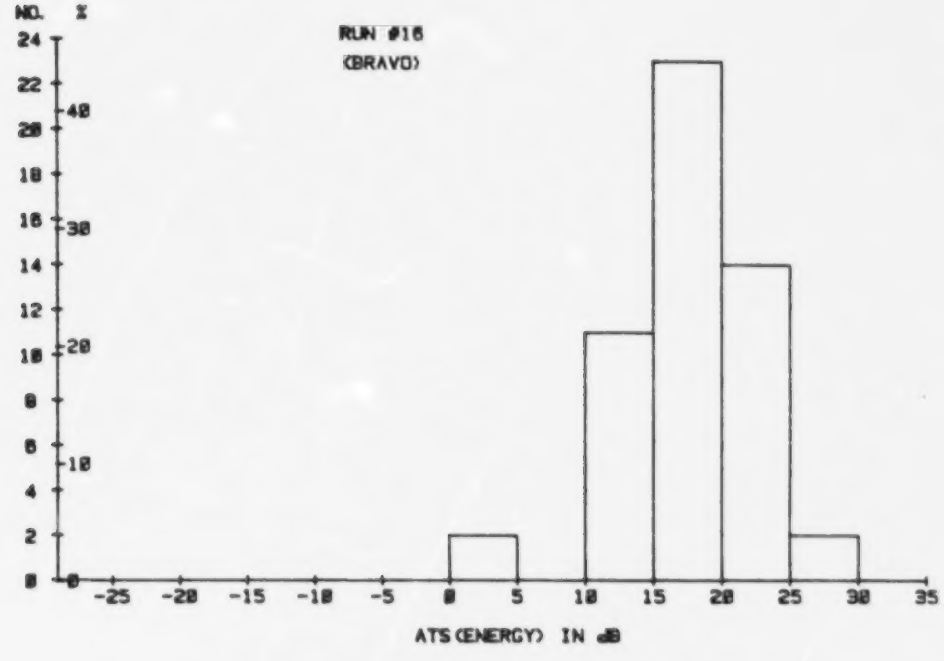
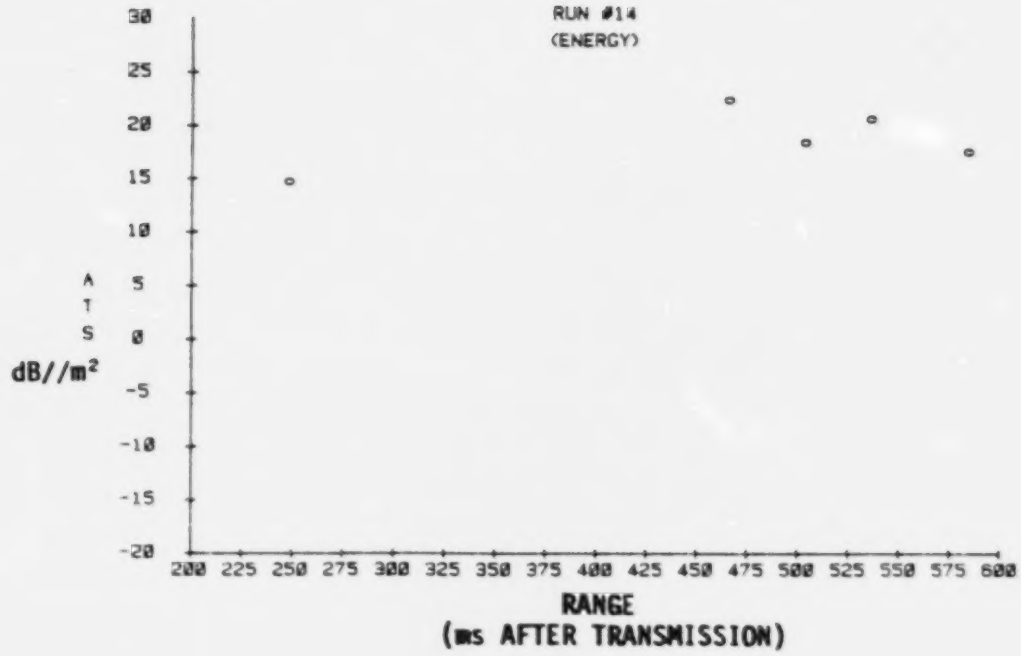


Figure A16 Iceberg #3, Run #16, Target Strength Statistics



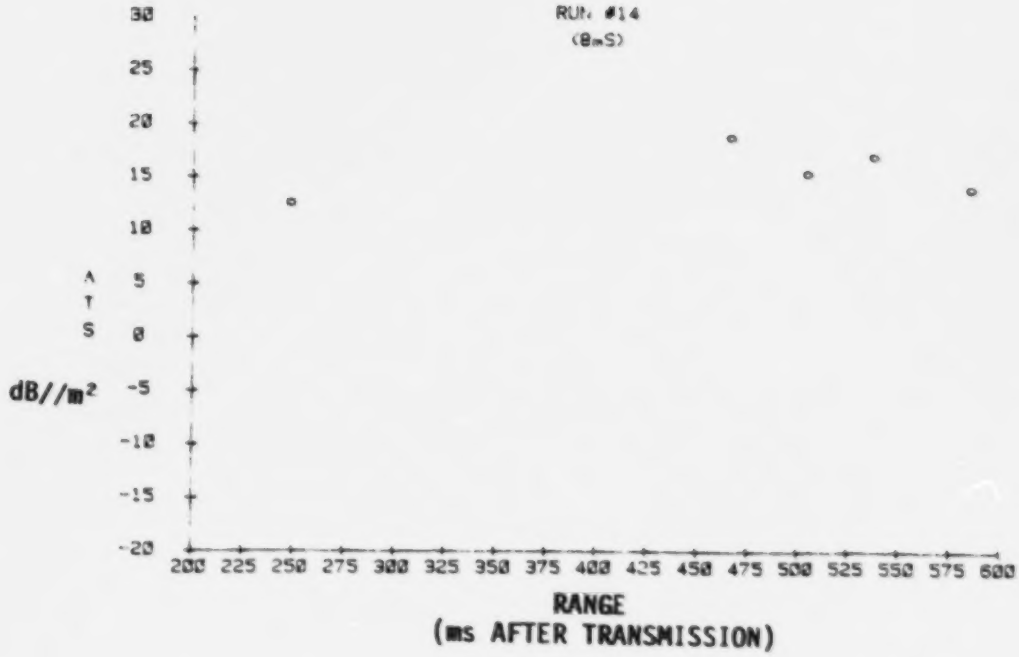


Figure A17 Iceberg #3, Run #14, Acoustic Target Strength

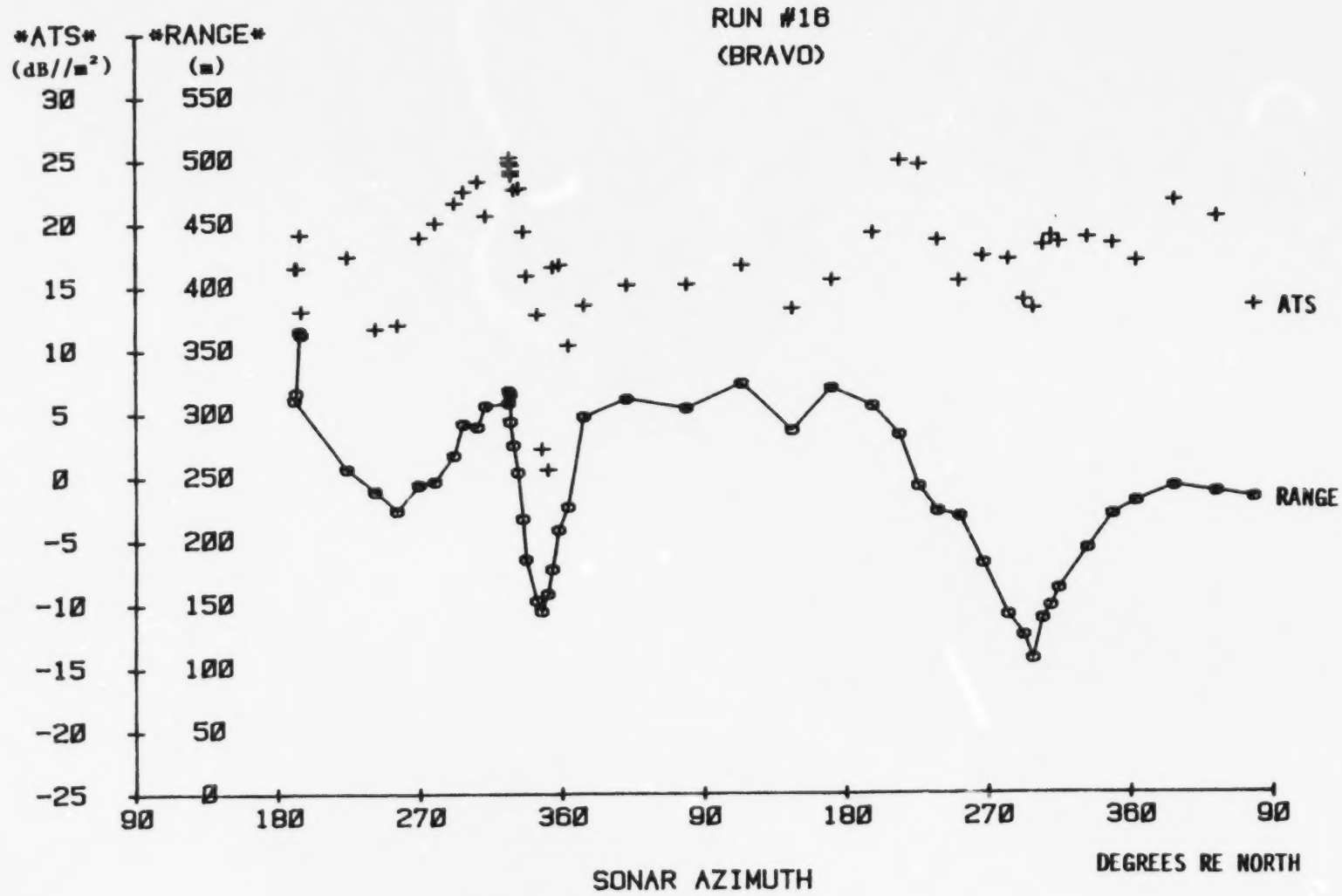


Figure A18 Iceberg #3, Run #14, Acoustic Target Strength and Range vs. Sonar Azimuth

DATA SUMMARY ICEBERG NO. 4

Sea State 1 to 2

Wind Speed Not recorded

Water Depth Not recorded

Date	Run No.	Run Type	Comments
28 July	17	Alpha	3 out of 10 readings used
28 July	18	Alpha	15 out of 15; iceberg turning at 2°/s

ICEBERG DESCRIPTION

Height above waterline	8 m
Length at waterline	50 m
Estimated Draught	30 m
Iceberg Classification	Small picturesque berg, dry dock

TARGET STRENGTH MEASUREMENTS

Number of Estimates 18

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	- 8.56	- 5.14
Standard Deviation dB	5.21	3.79
Median	-10.37	- 7.18
10th Percentile	- 1.44	- .92
90th Percentile	-13.41	- 9.13

ICEBERG #Ø4

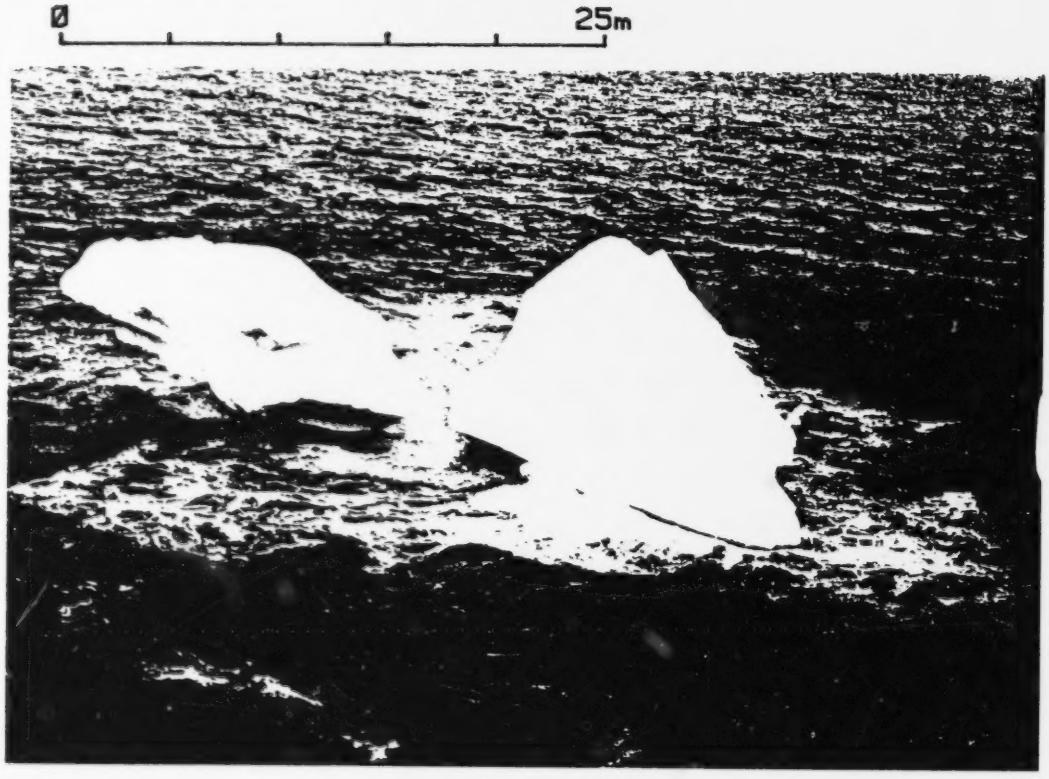


PLATE A4

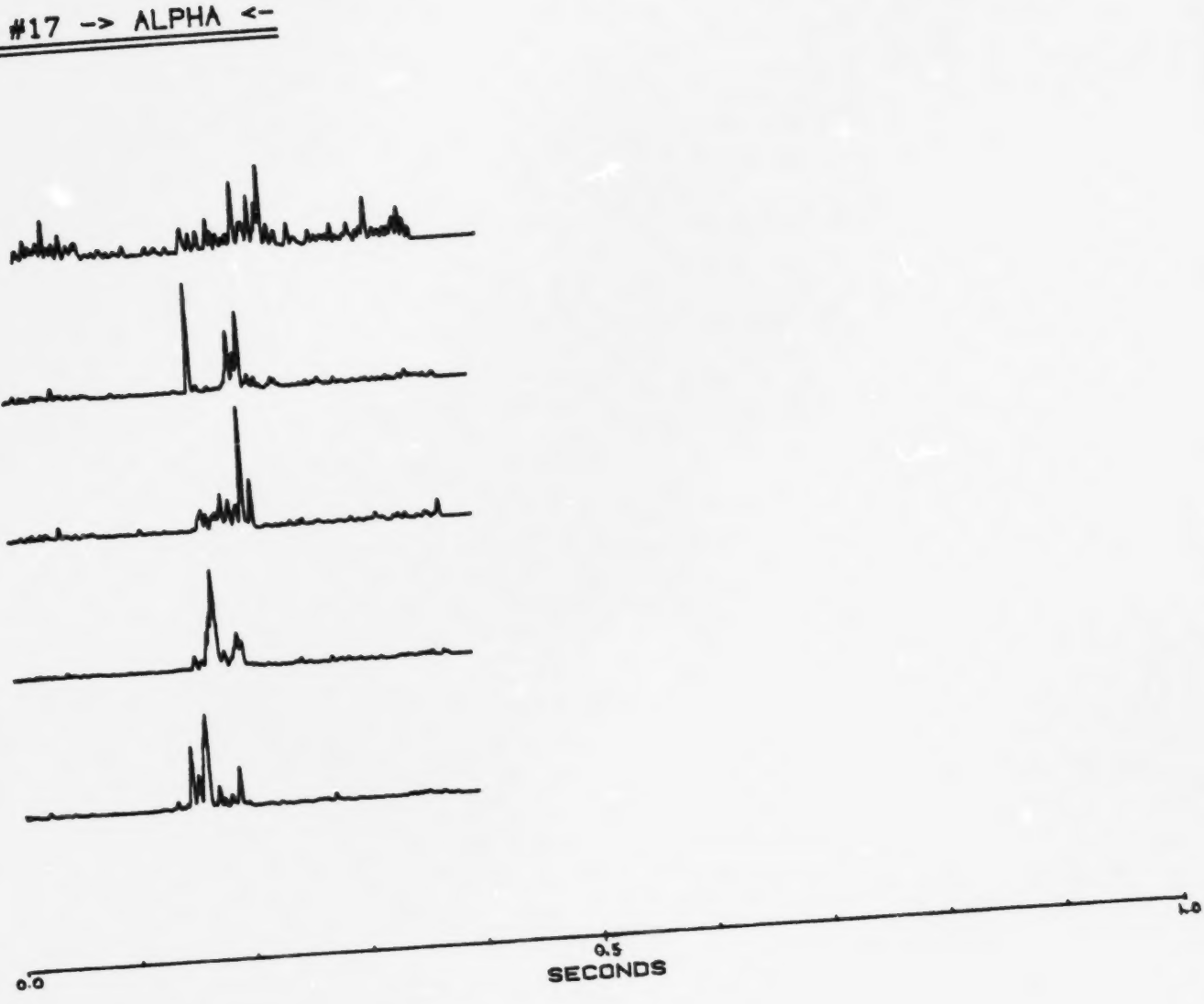


Figure A19 Iceberg #4, Run #17, Representative Echo Power Envelope

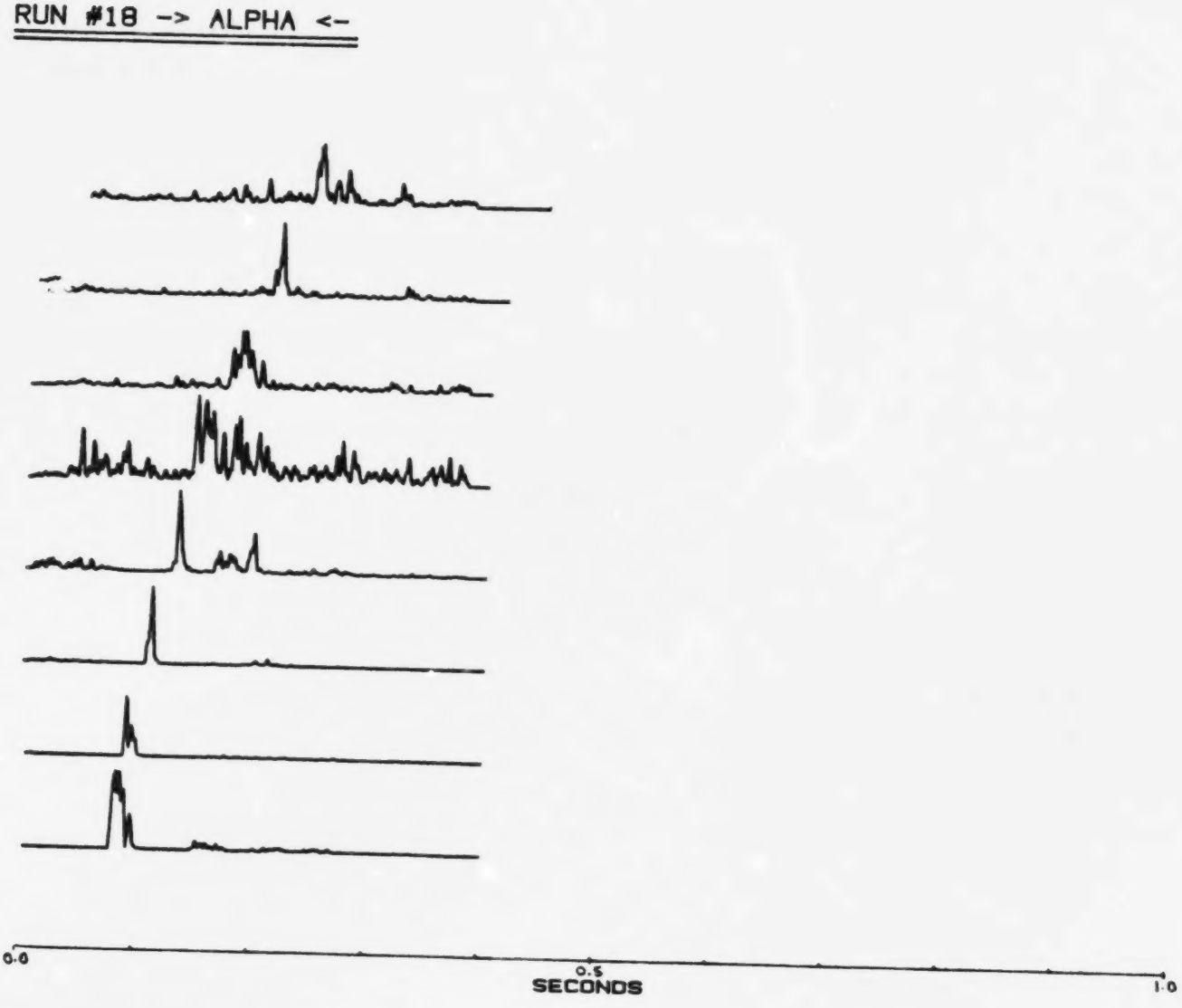
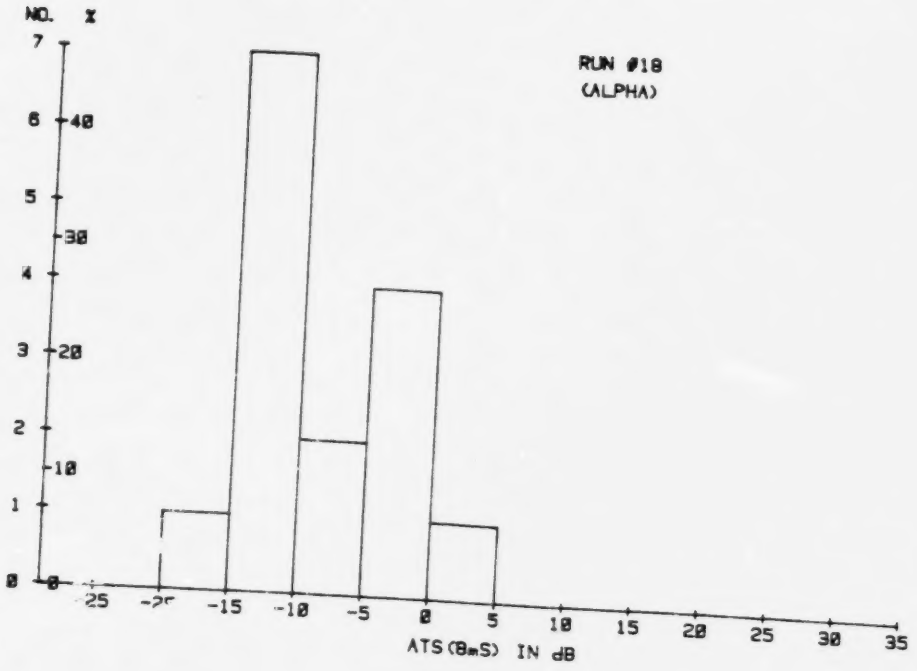


Figure A20 Iceberg #4, Run #18, Representative Echo Power Envelope



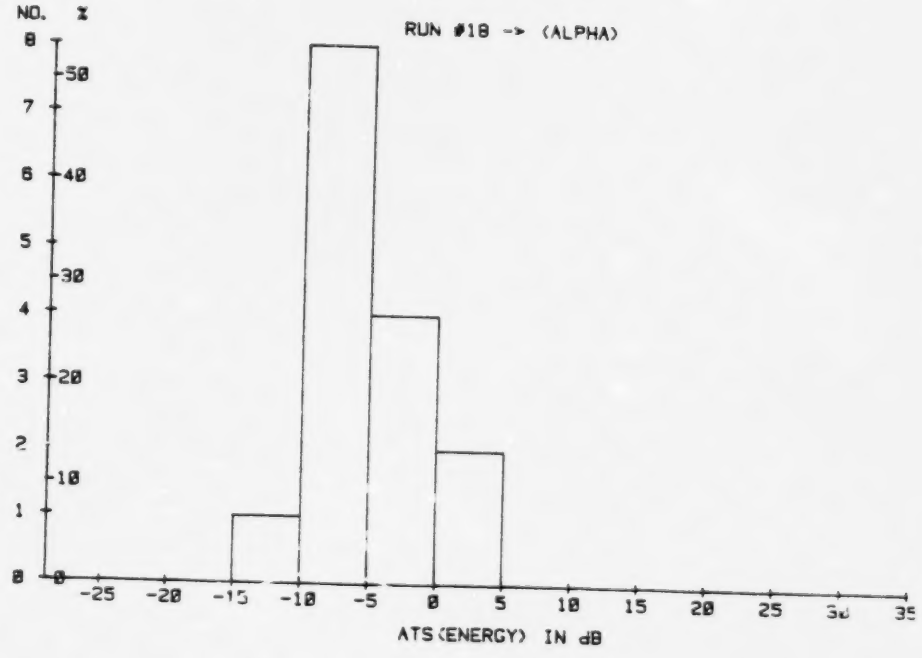
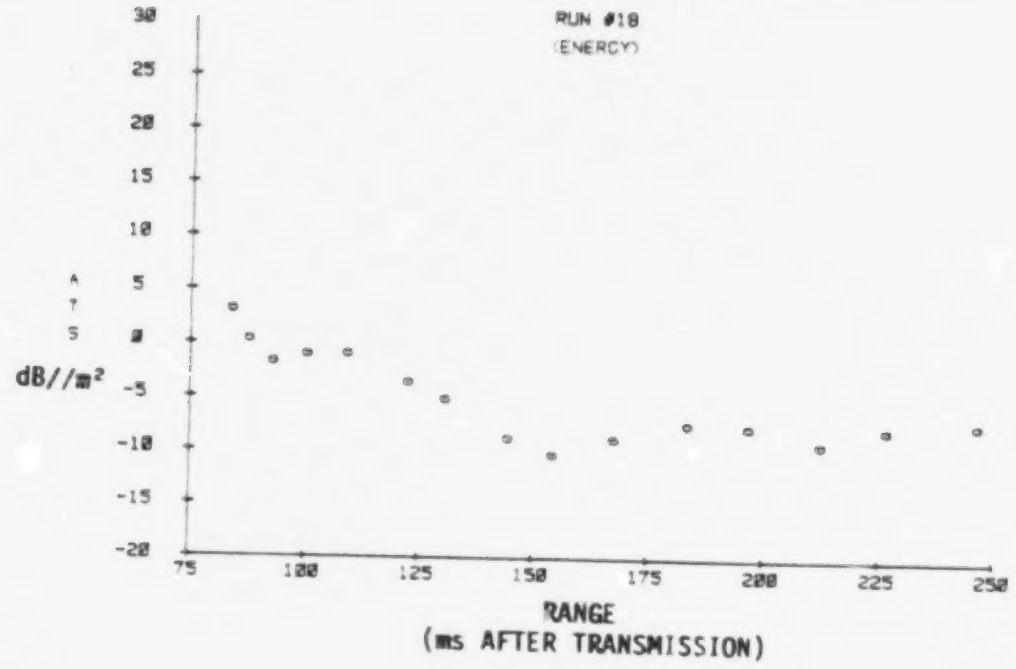


Figure A21 Iceberg #4, Run #18, Target Strength Statistics



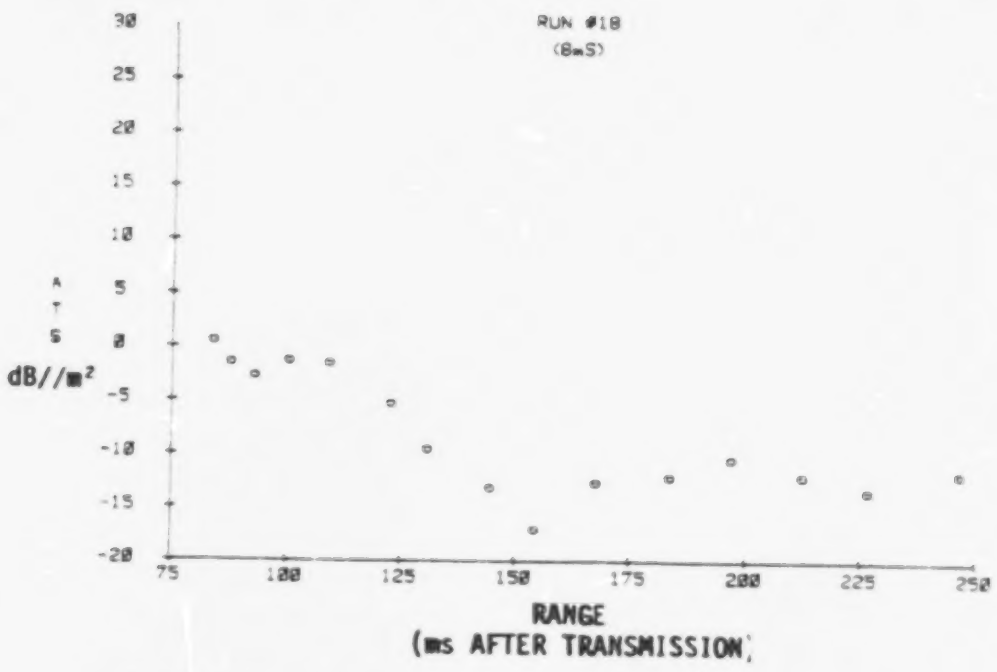


Figure A23 Iceberg #4, Run #38, Acoustic Target Strength

DATA SUMMARY ICEBERG NO. 5

Sea State 3 to 4 Wind Speed 40 knots

Water Depth 140 m

Date	Run No.	Run Type	Comments
29 July	23	Alpha	15 of 36 readings used; large grounded berg with arch; plenty of bubbles around it.
29 July	24	Bravo	22 or 32 readings; counter-clockwise; audio beam on part of berg

ICEBERG DESCRIPTION

Height above waterline	82.7 m
Length at waterline	212 m
Estimated Draught	140 m
Iceberg Classification	Large berg

TARGET STRENGTH MEASUREMENTS

Number of Estimates 37

PARAMETER	PEAK VALUE (3 ms)	TOTAL ENERGY
Average Target Strength dB	12.11	17.14
Standard Deviation dB	9.11	8.57
Median dB	13.55	19.31
10th Percentile dB	20.87	25.32
90th Percentile dB	- 1.47	4.64

ICEBERG #05

0 200m

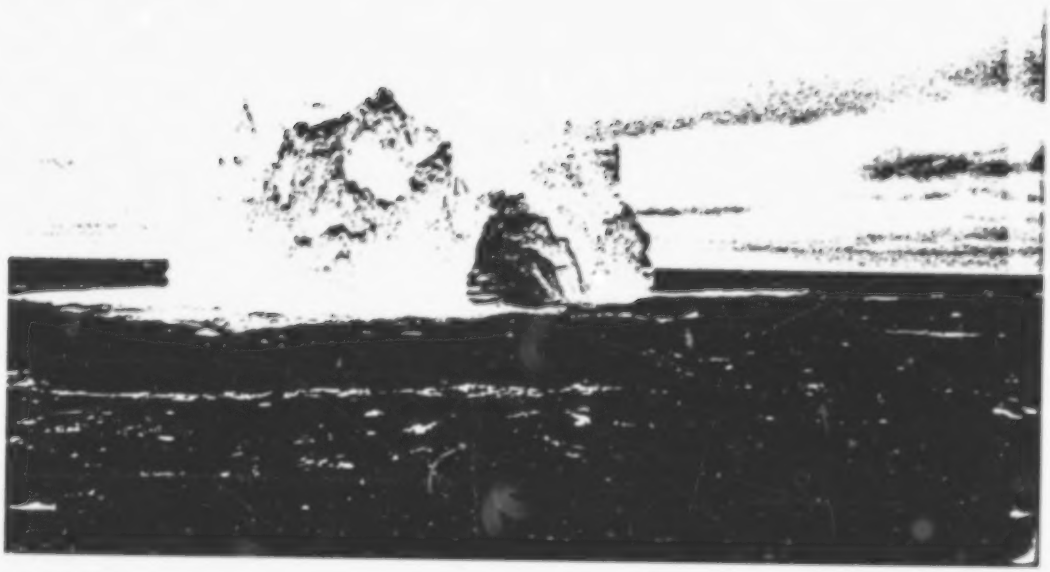


PLATE A5

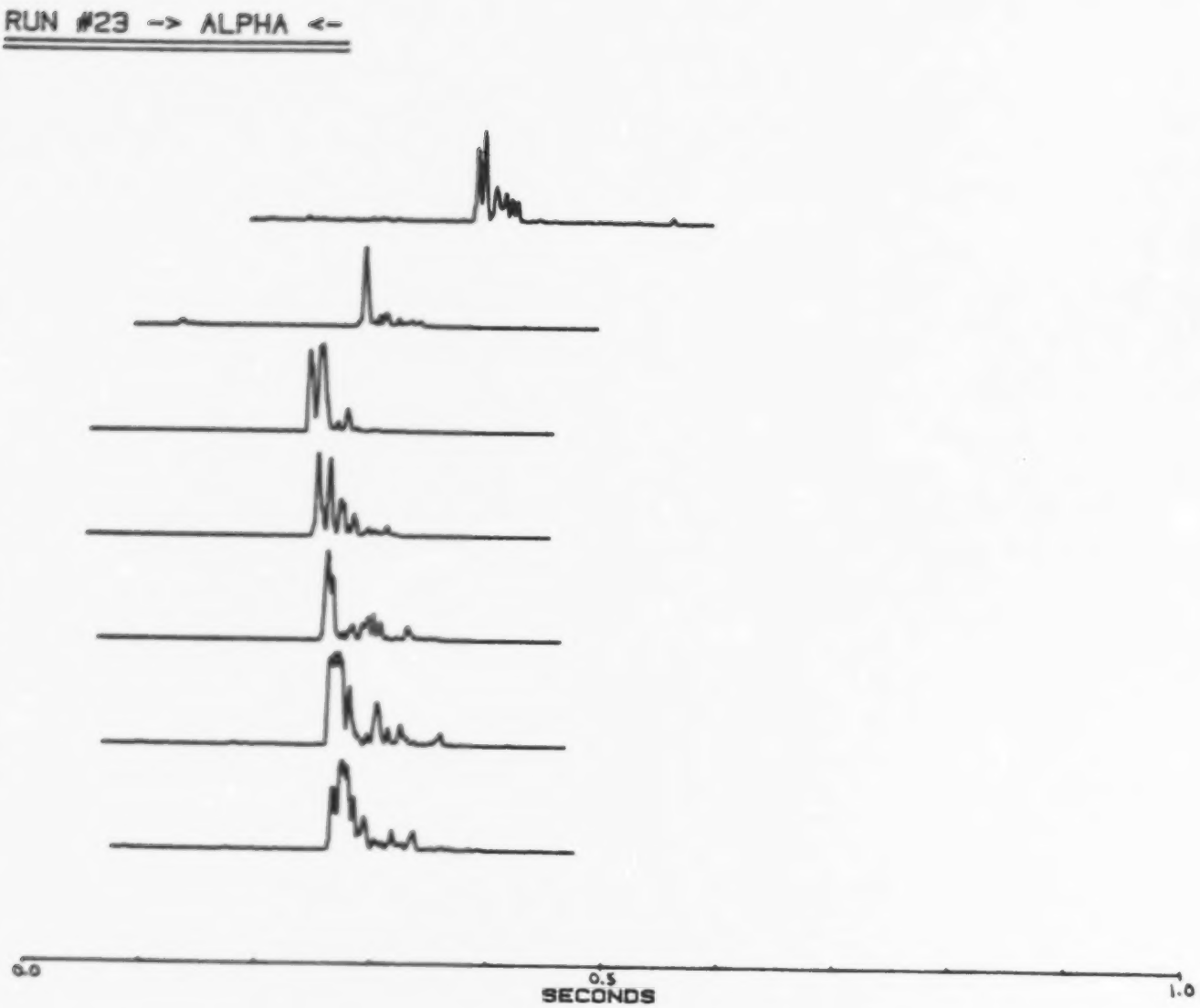


Figure A24 Iceberg #5, Run #23, Representative Echo Power Envelope

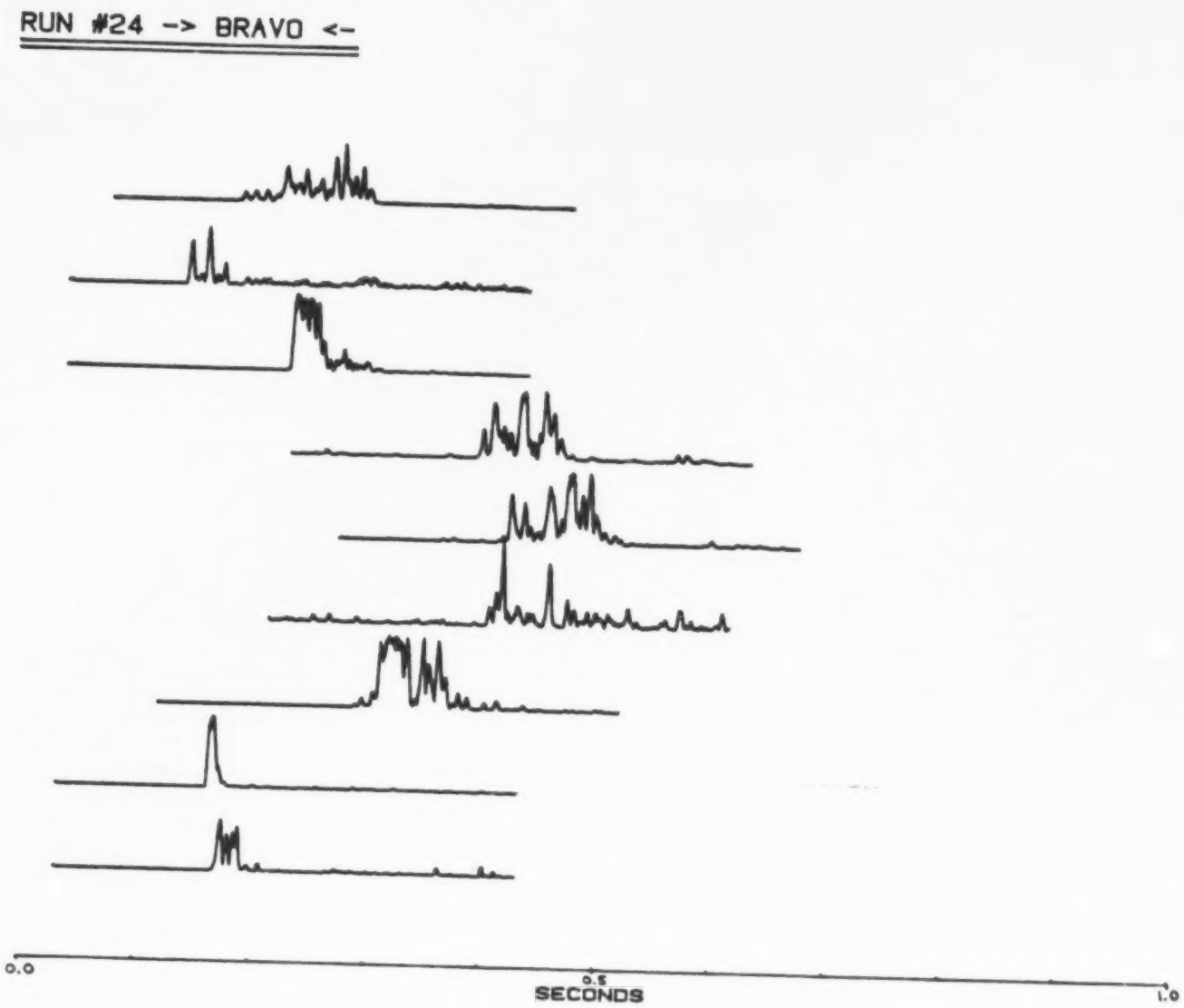
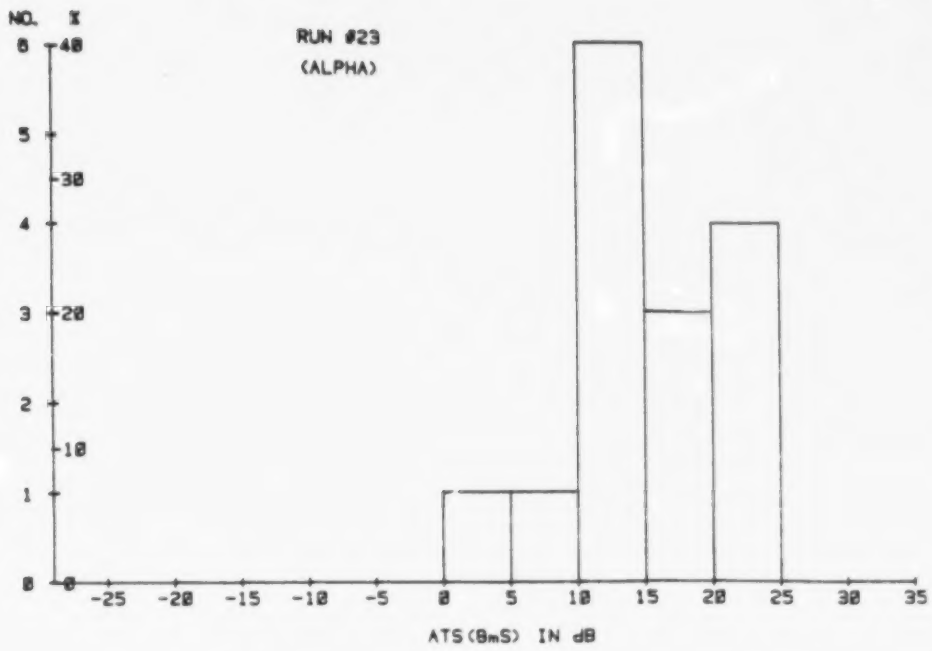


Figure A25 Iceberg #5, Run #24, Representative Echo Power Envelope



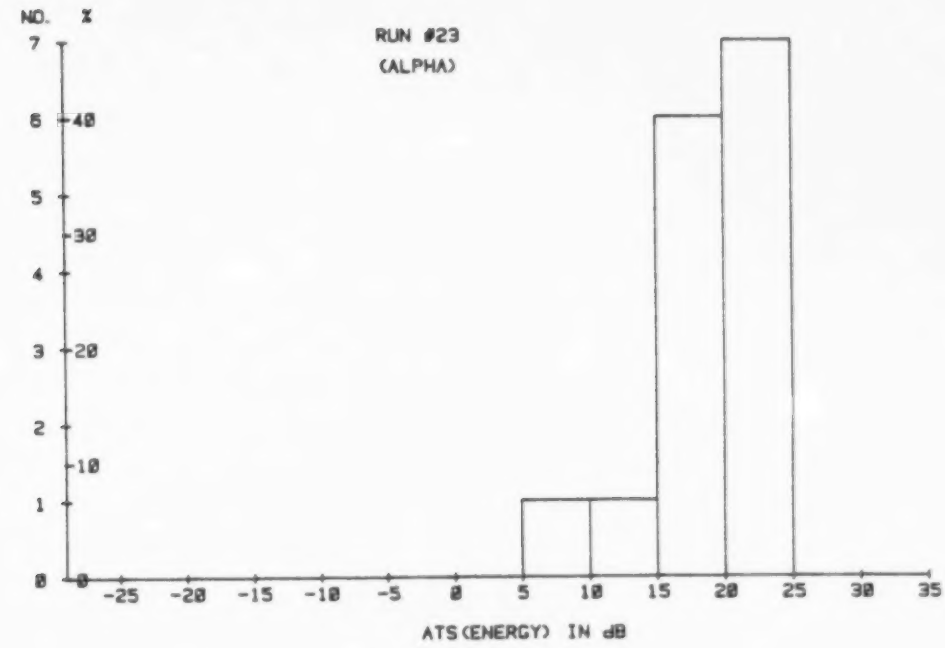
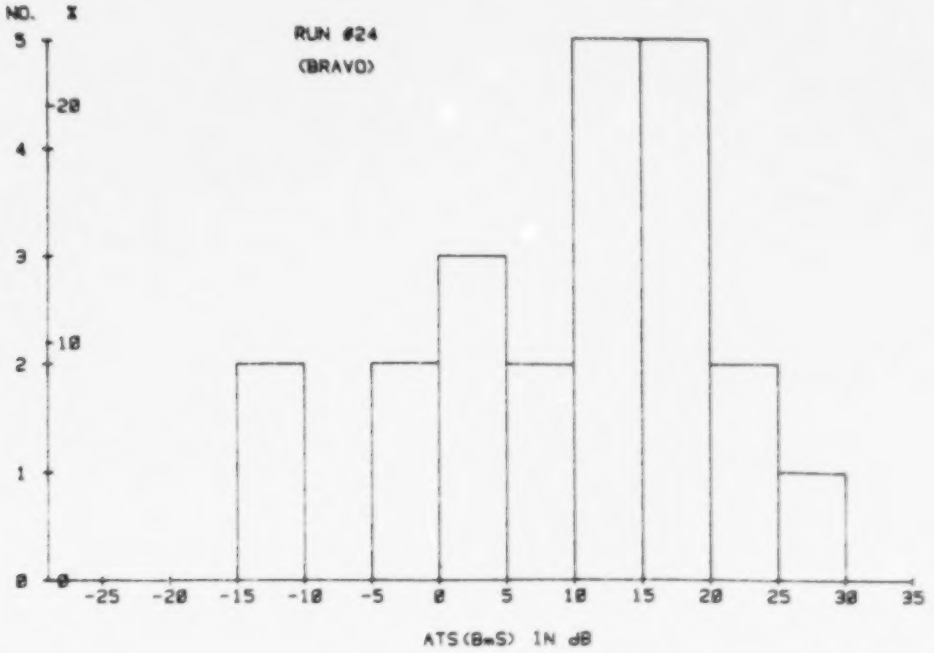


Figure A26 Iceberg #5. Run #23, Target Strength Statistics



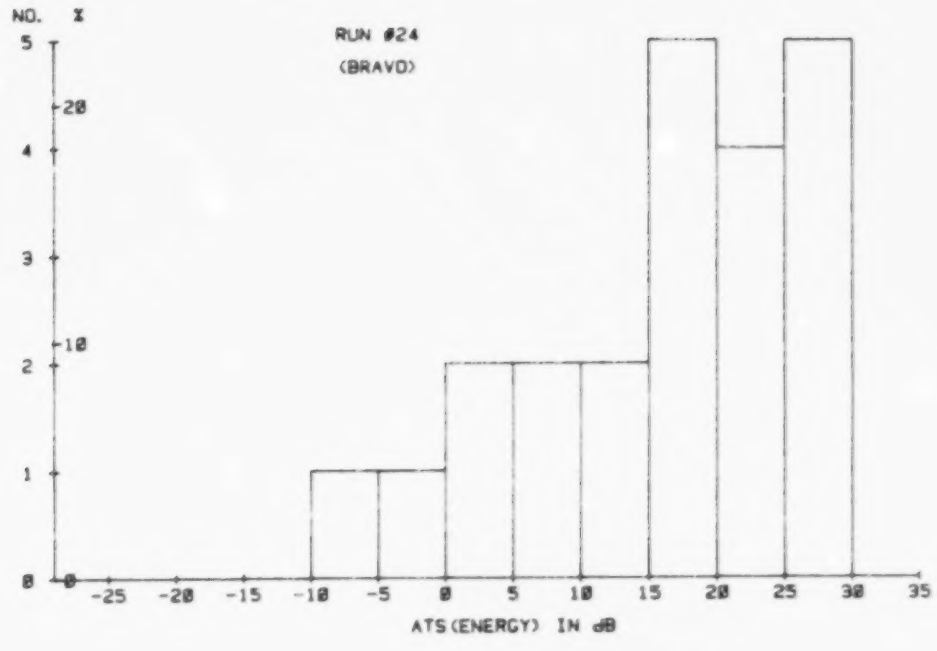
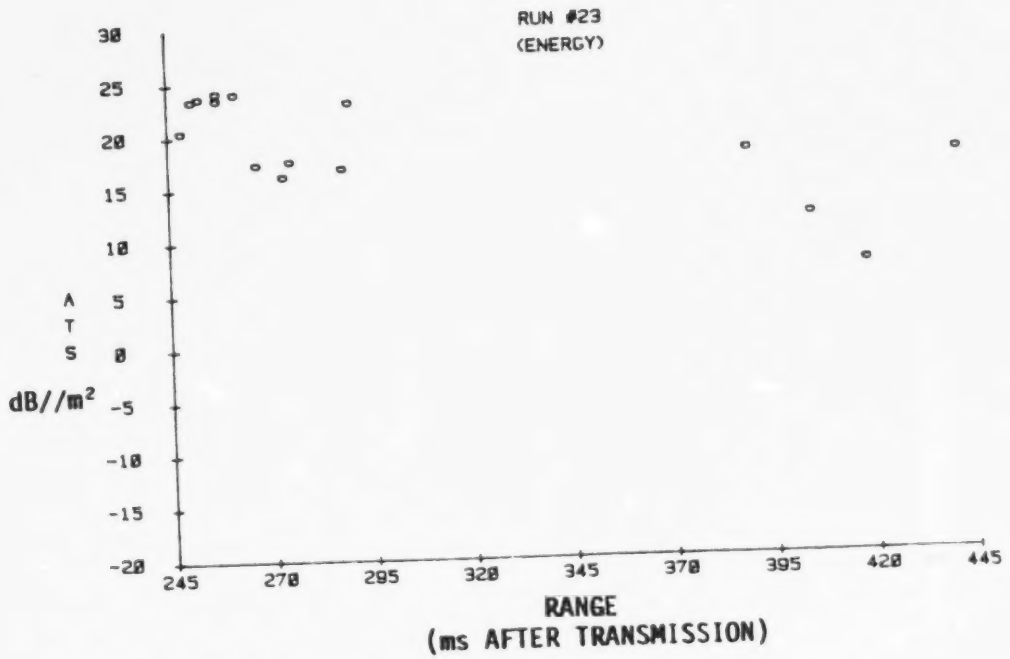


Figure A27 Iceberg # , Run #24, Target Strength Statistics



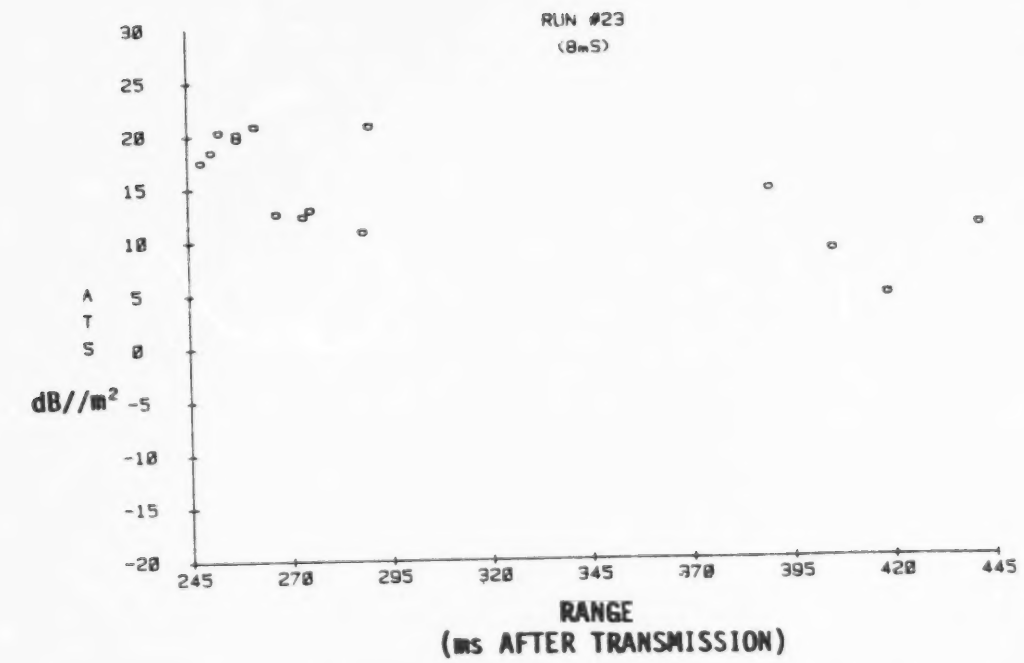


Figure A28 Iceberg #5, Run #23, Acoustic Target Strength

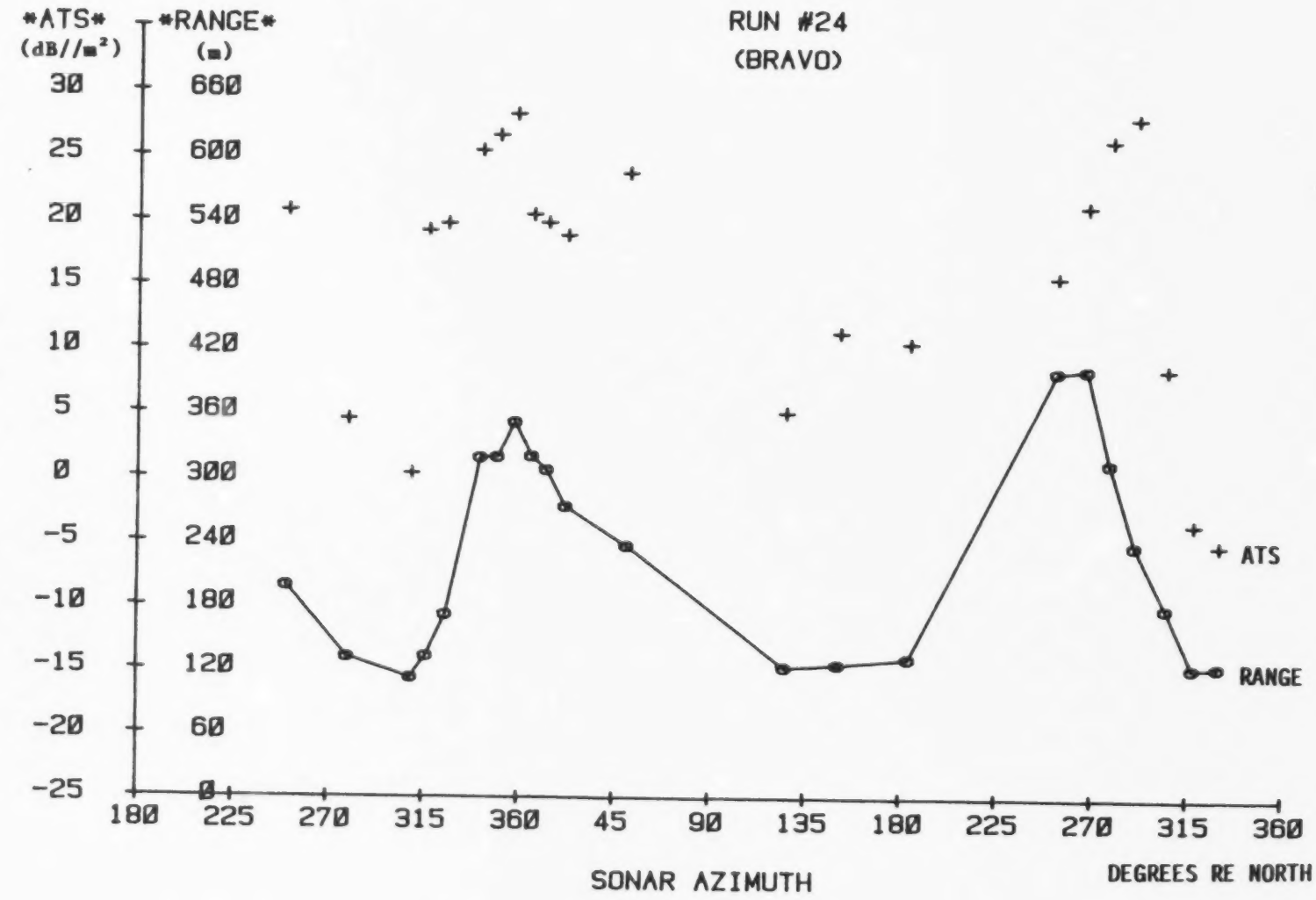


Figure A29 Iceberg #5, Run #24, Acoustic Target Strength and Range vs. Sonar Azimuth

DATA SUMMARY ICEBERG NO. 6

Sea State 3 to 4

Wind Speed 40 knots

Water Depth 140 m

Date	Run No.	Run Type	Comments
29 July	25	Alpha/Drift	26 of 45 readings; sometimes double target was detected
29 July	26	Alpha	3 of 11 readings used.
29 July	27	Bravo (counter-clockwise)	25 of 48 readings; also receiving echoes from bottom

ICEBERG DESCRIPTION

Height above waterline 34 m
Length at waterline 161 m
Estimated Draught 135 m
Iceberg Classification Large berg, blocky

TARGET STRENGTH MEASUREMENTS

Number of Estimates 54

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	13.56	17.84
Standard Deviation dB	4.23	4.46
Median dB	14.0	18.72
10th Percentile dB	18.89	23.44
90th Percentile dB	7.56	11.71

ICEBERG #06

0 50m

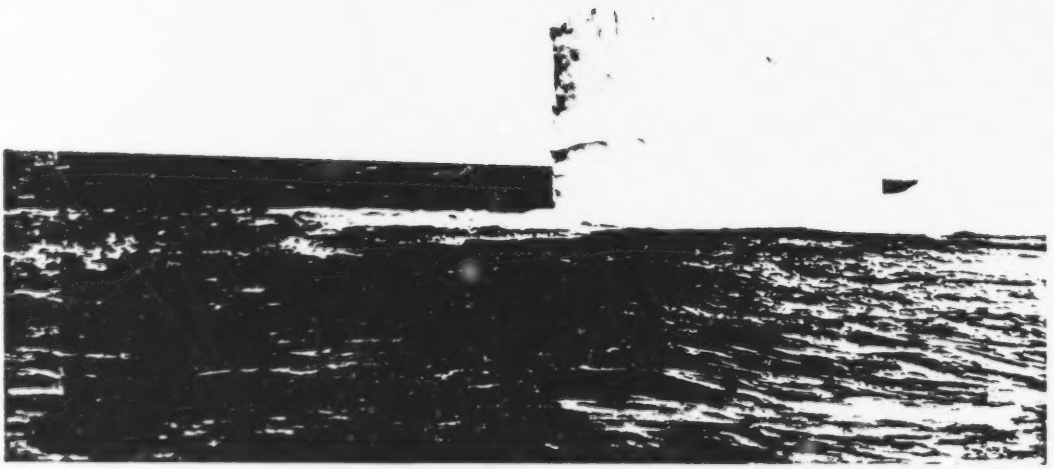


PLATE A6

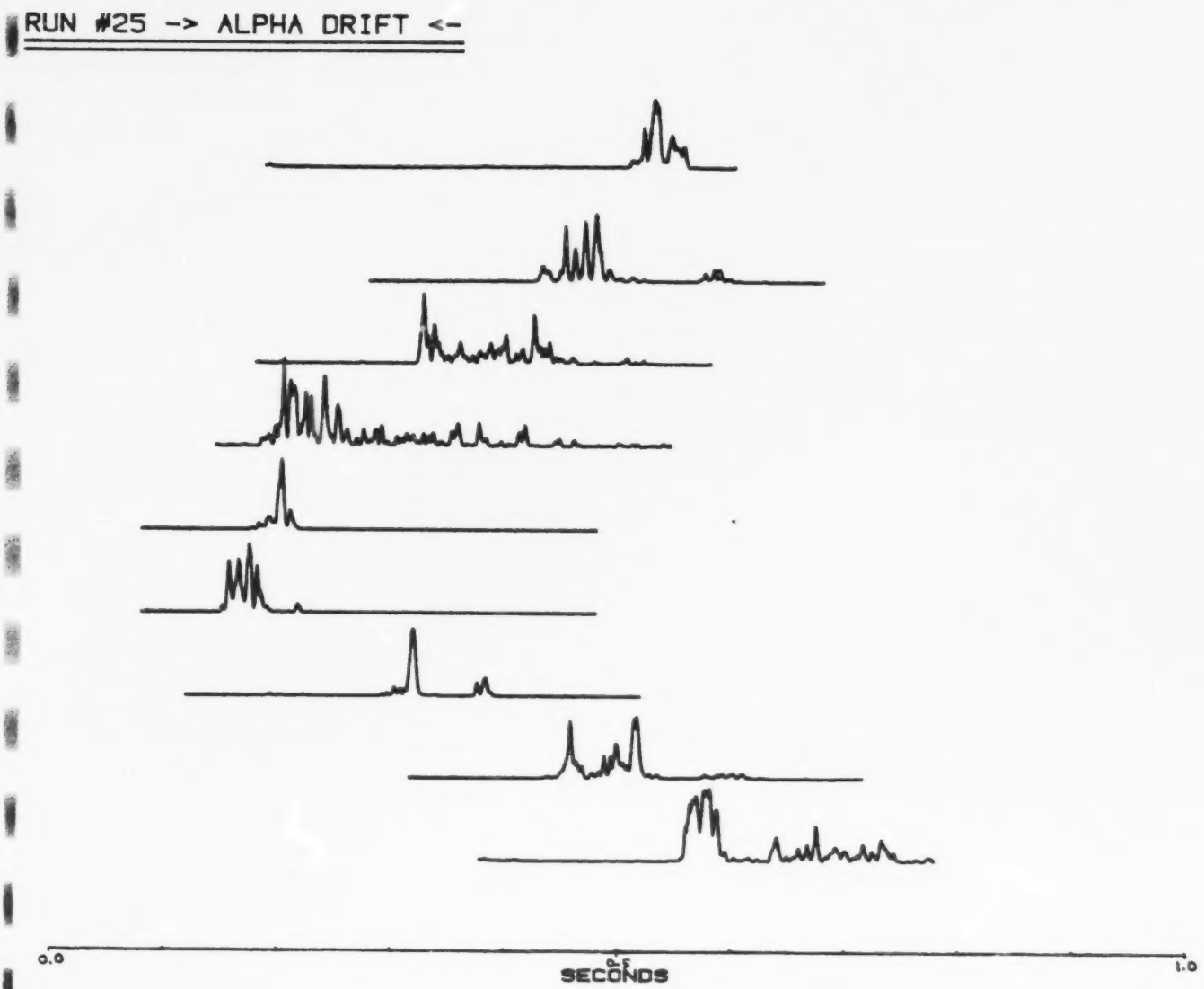


Figure A30 Iceberg #6, Run #25, Representative Echo Power Envelope

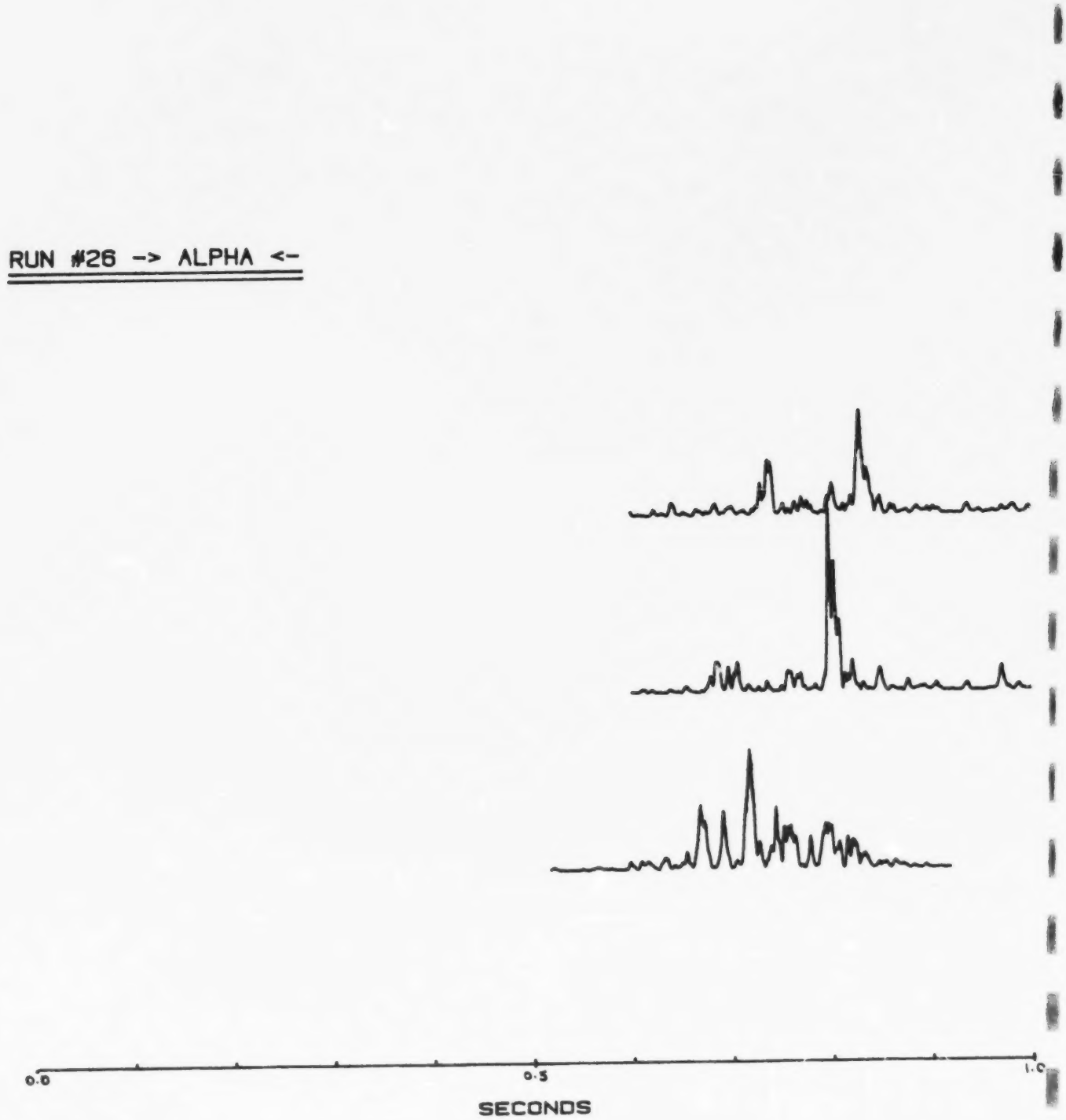


Figure A31 Iceberg #6, Run #26, Representative Echo Power Envelope

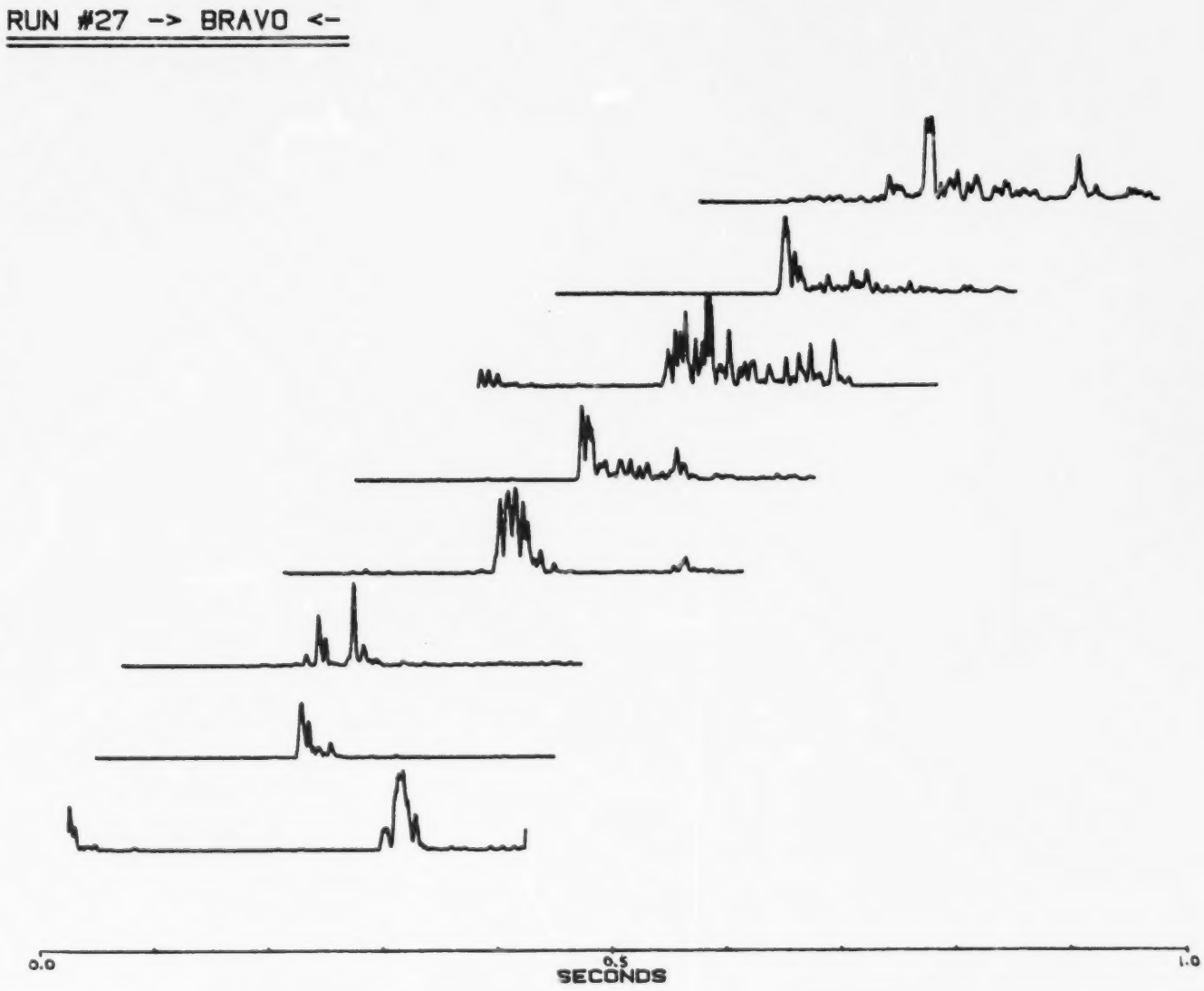
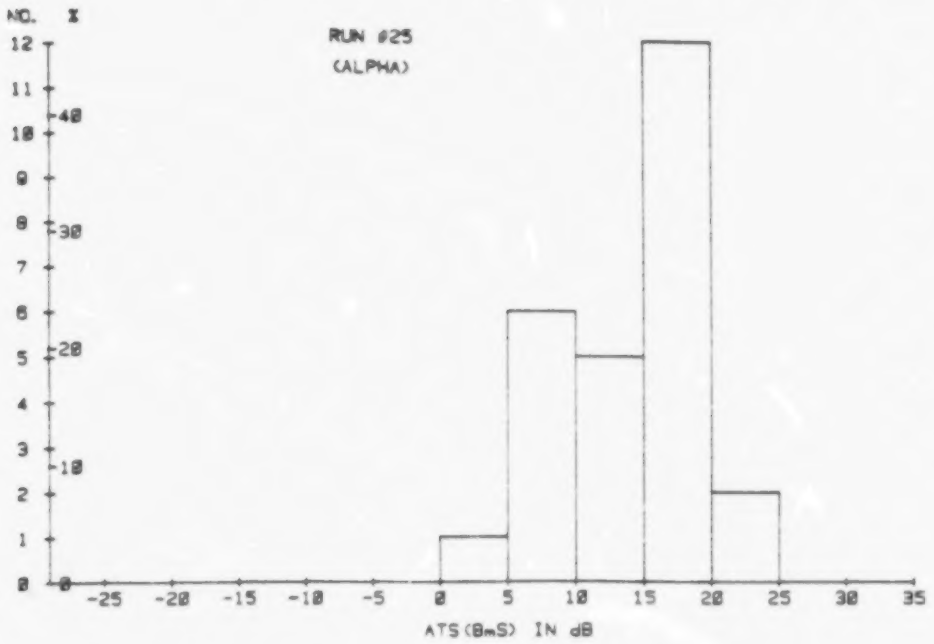


Figure A32 Iceberg #6, Run #27, Representative Echo Power Envelope



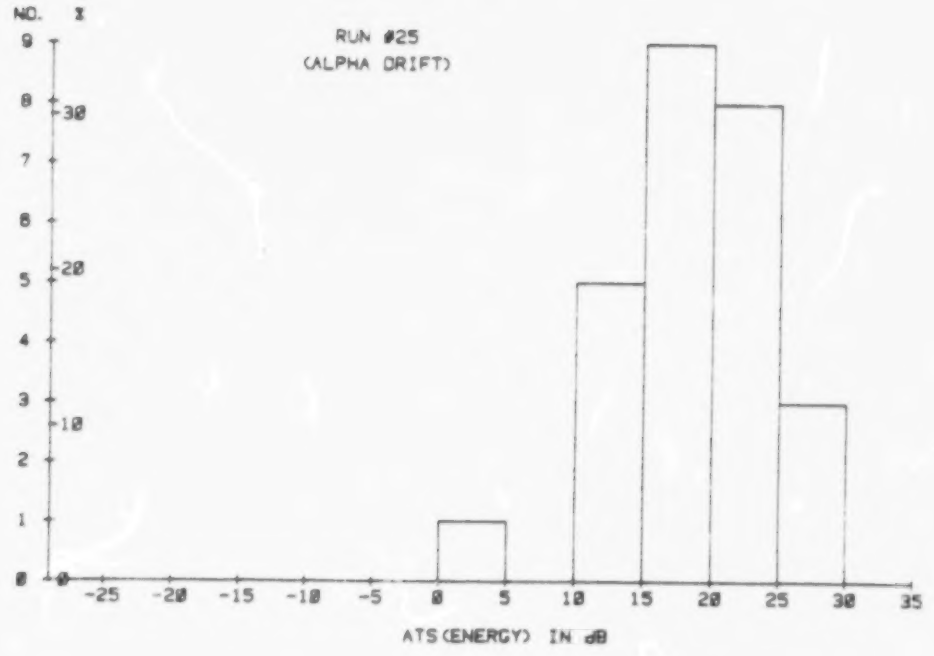
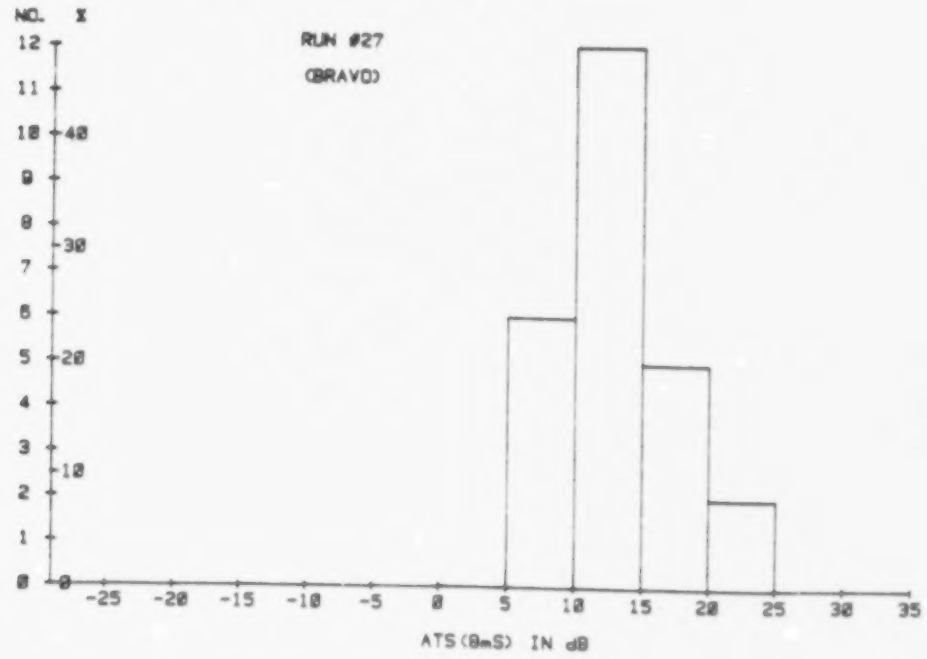


Figure A33 Iceberg #6, Run #25, Target Strength Statistics



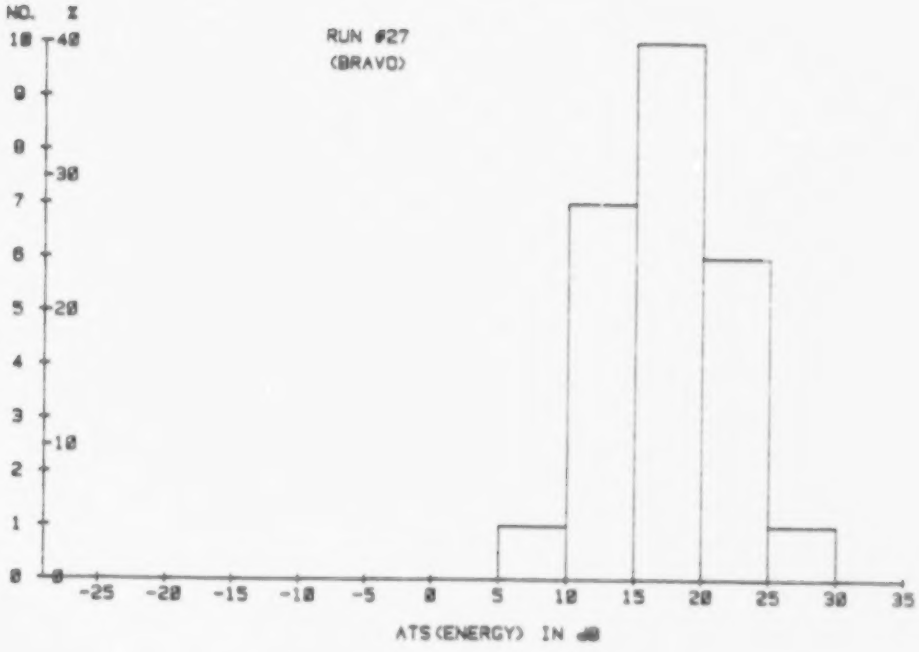


Figure A34 Iceberg #6, Run #27, Target Strength Statistics

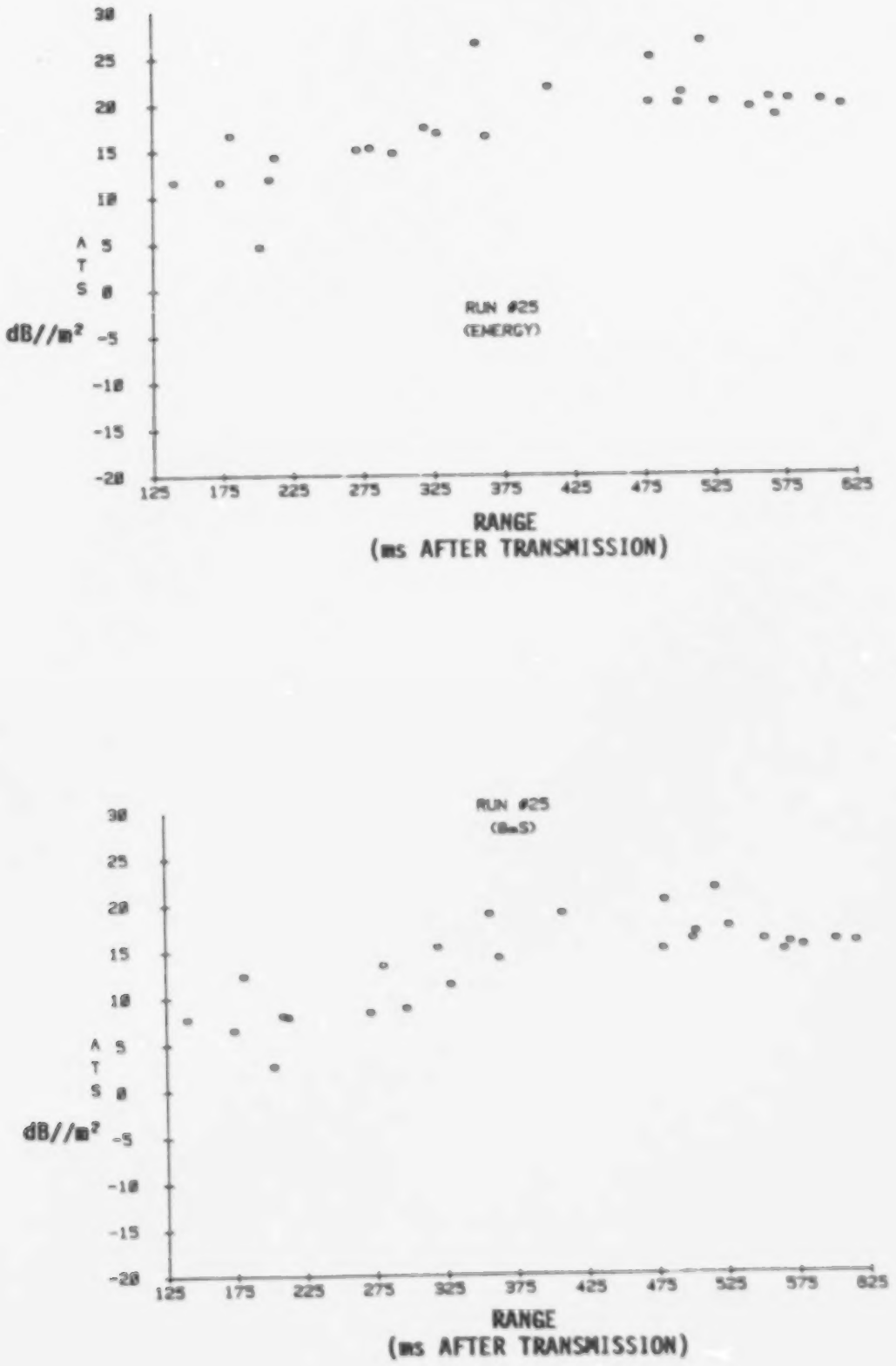


Figure A35 Iceberg #6, Run #25, Acoustic Target Strength

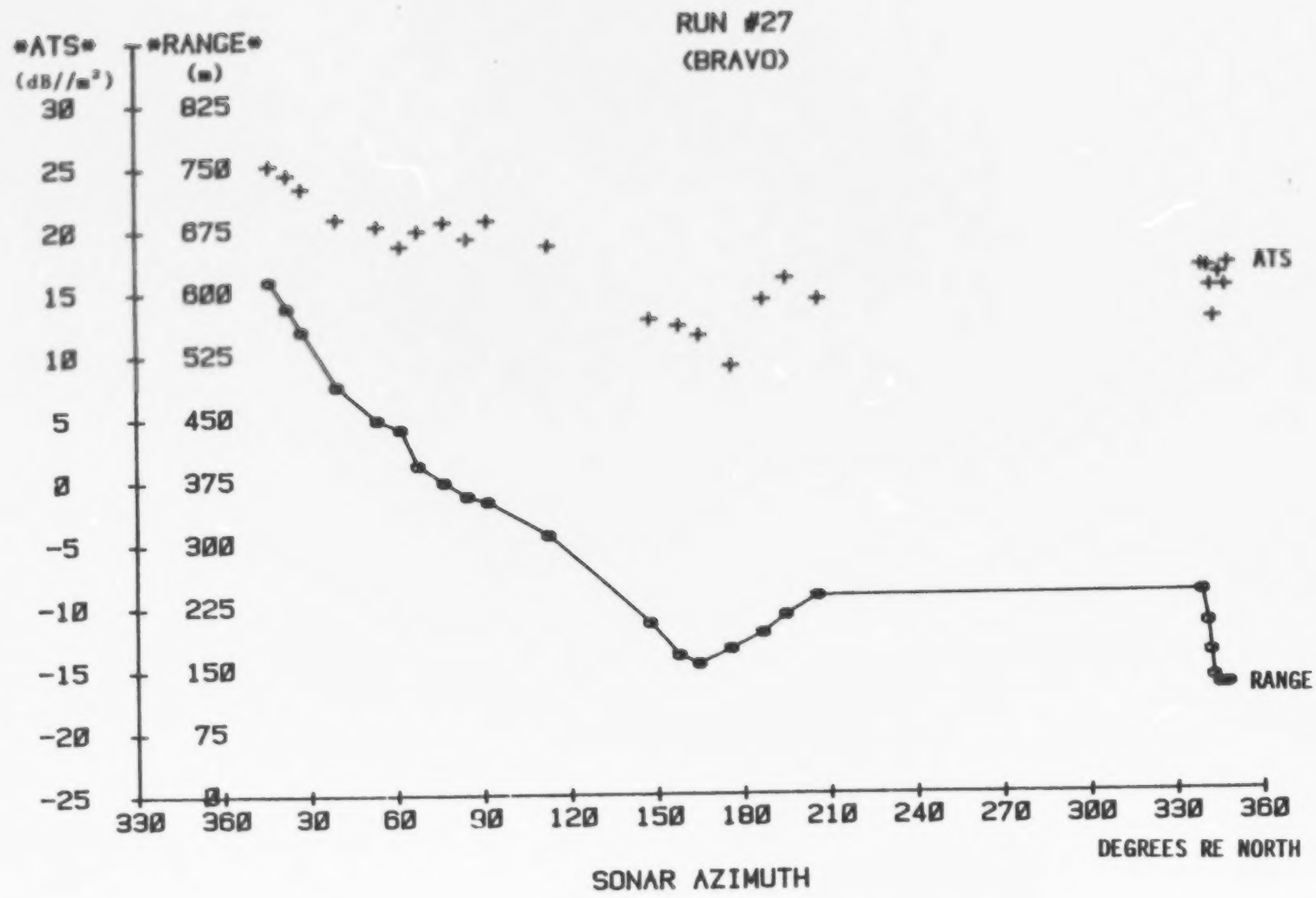


Figure A36 Iceberg #6, Run #27, Acoustic Target Strength and Range vs. Sonar Azimuth

DATA SUMMARY ICEBERG NO. 7

Sea State 3

Wind Speed Not recorded

Water Depth 140 m

Date	Run No.	Run Type	Comments
30 July	28	Alpha	12 out of 80 readings used

ICEBERG DESCRIPTION

Height above waterline 11 m
Length at waterline 25 m
Estimated Draught 30 m
Iceberg Classification Small berg, weathered

TARGET STRENGTH MEASUREMENTS

Number of Estimates 12

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	7.02	12.33
Standard Deviation dB	1.47	1.23
Median dB	7.18	12.29
10th Percentile dB	8.48	13.74
90th Percentile dB	3.99	9.79

ICEBERG #07

Ø 50m

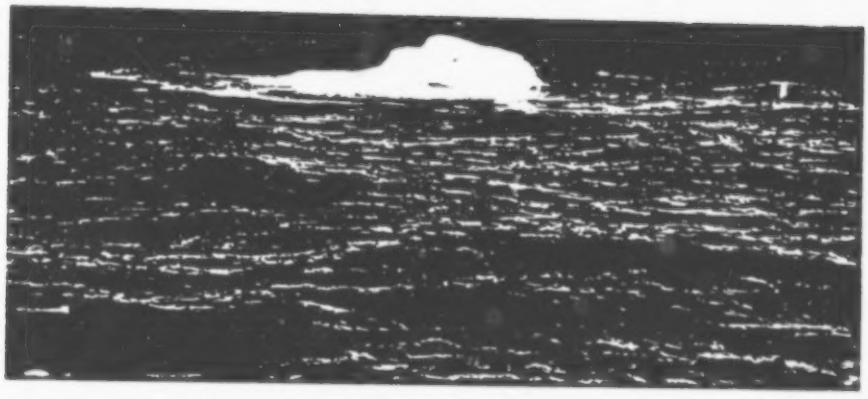


PLATE A7

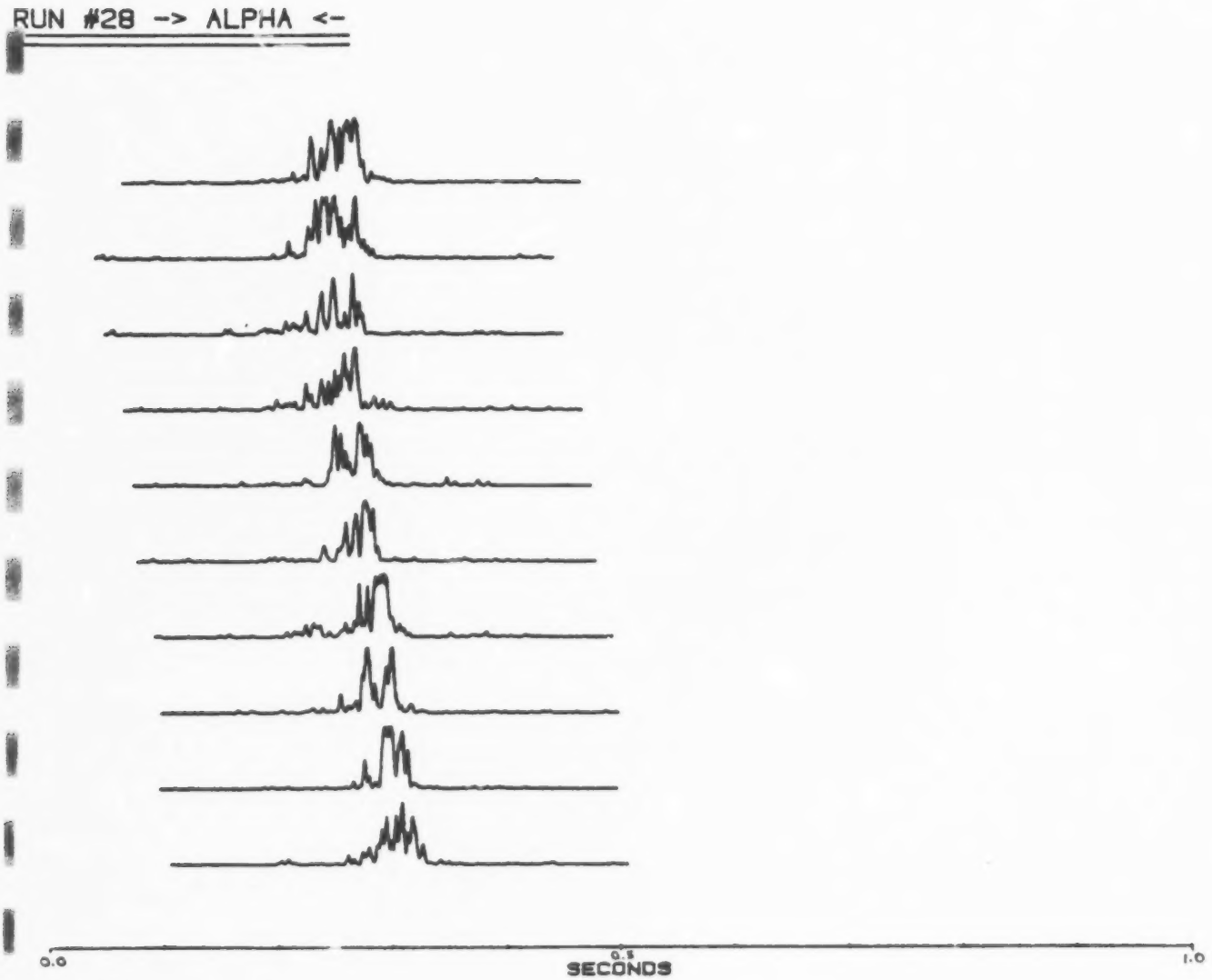
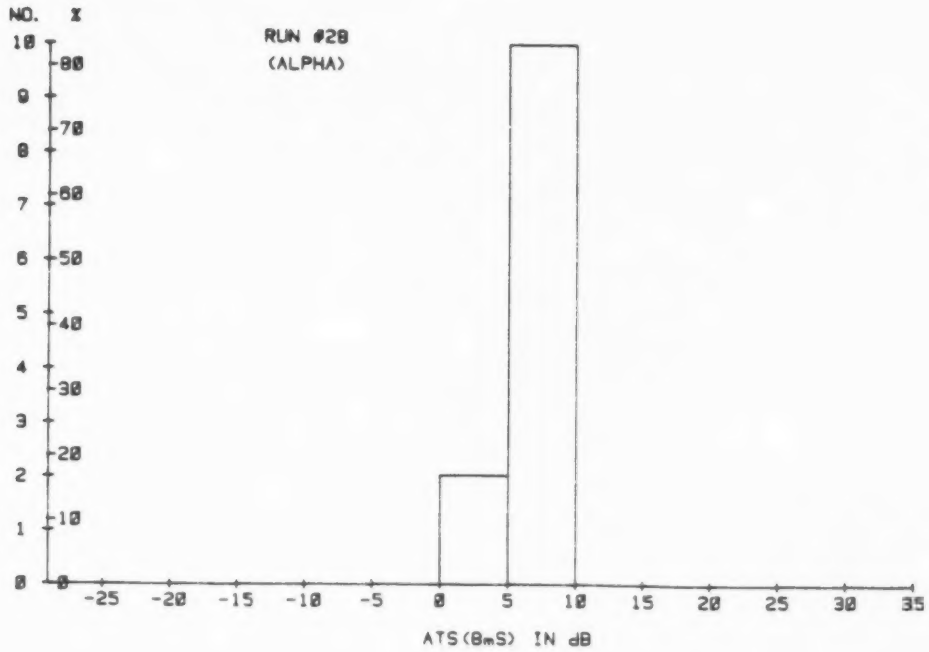


Figure A37 Iceberg #7, Run #28, Representative Echo Power Envelope



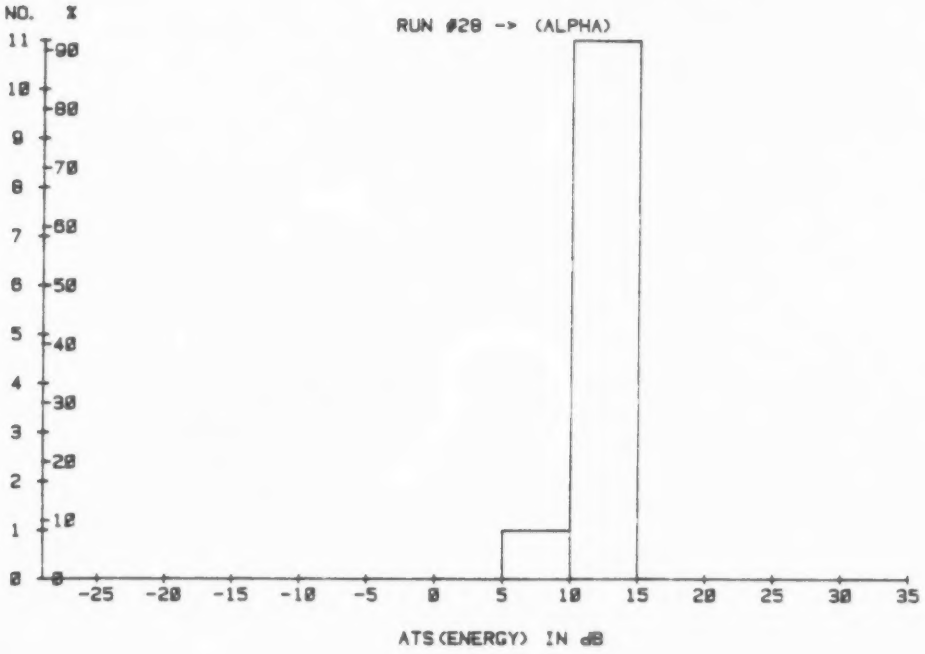
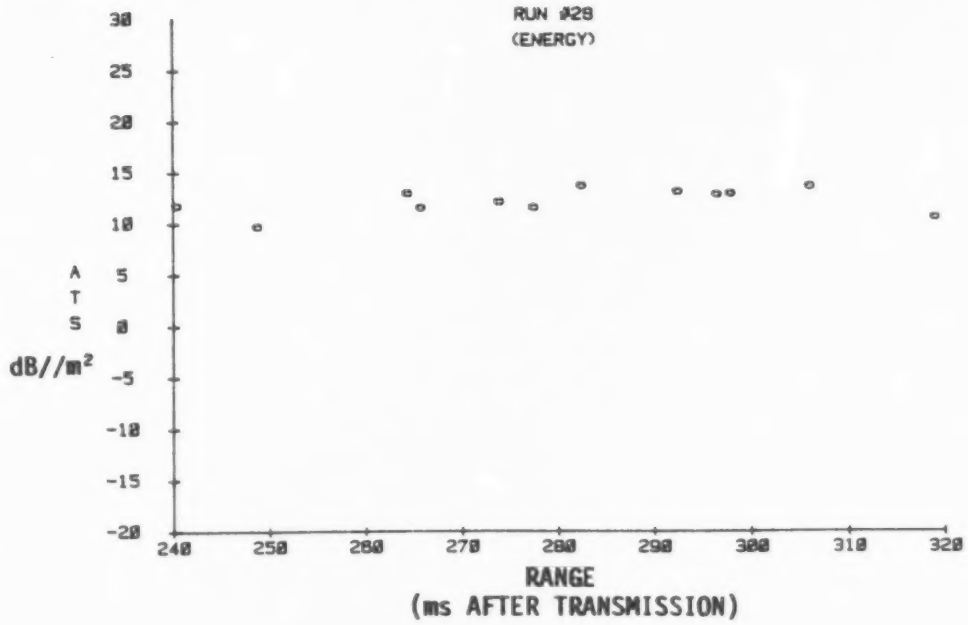


Figure A38 Iceberg #7, Run #28, Target Strength Statistics



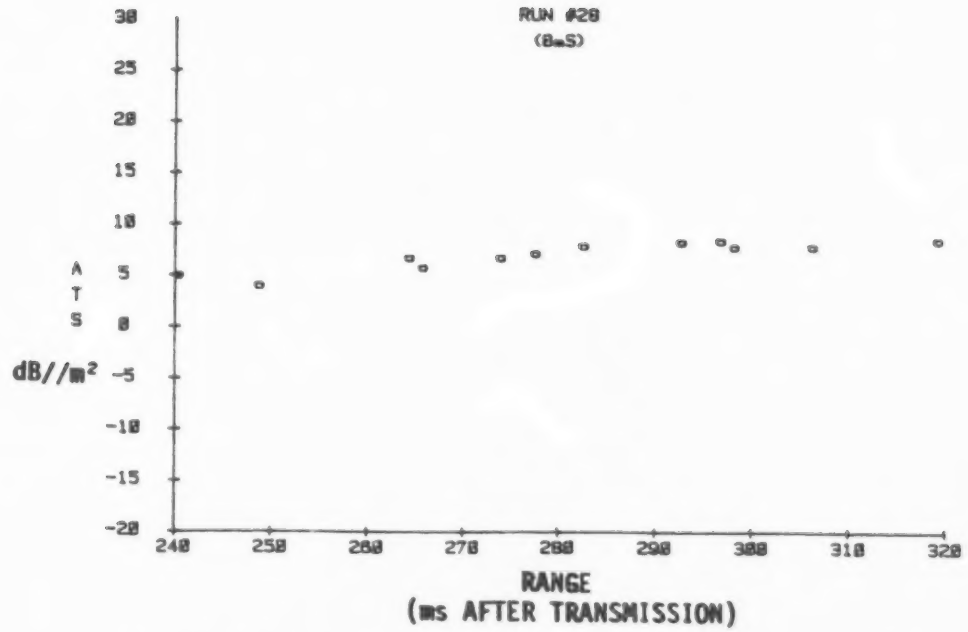


Figure A39 Iceberg #7, Run #28, Acoustic Target Strength

DATA SUMMARY ICEBERG NO. 8

Sea State 2

Wind Speed 12 knots

Water Depth 400 m

Date	Run No.	Run Type	Comments
30 July	29	Alpha	107 out of 116 readings used
30 July	31	Bravo (C.C.)	27 out of 50 readings used

ICEBERG DESCRIPTION

Height above waterline 63 m
Length at waterline 617 m (est. width is 200 m)
Estimated Draught 140 m
Iceberg Classification Very large berg

TARGET STRENGTH MEASUREMENTS

Number of Estimates 134

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	17.76	22.85
Standard Deviation dB	6.15	6.69
Median dB	18.44	23.54
10th Percentile dB	24.8	29.8
90th Percentile dB	11.73	16.73

ICEBERG #08

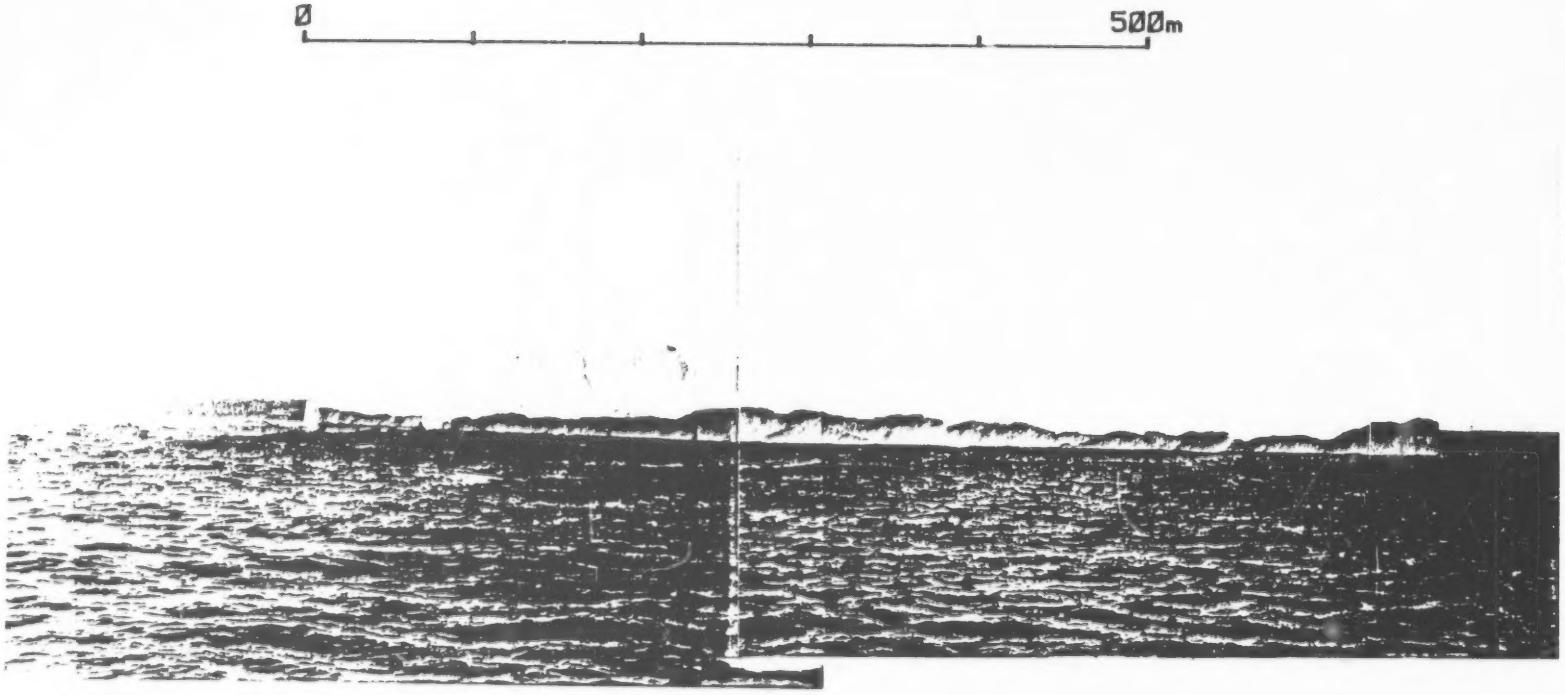


PLATE A8

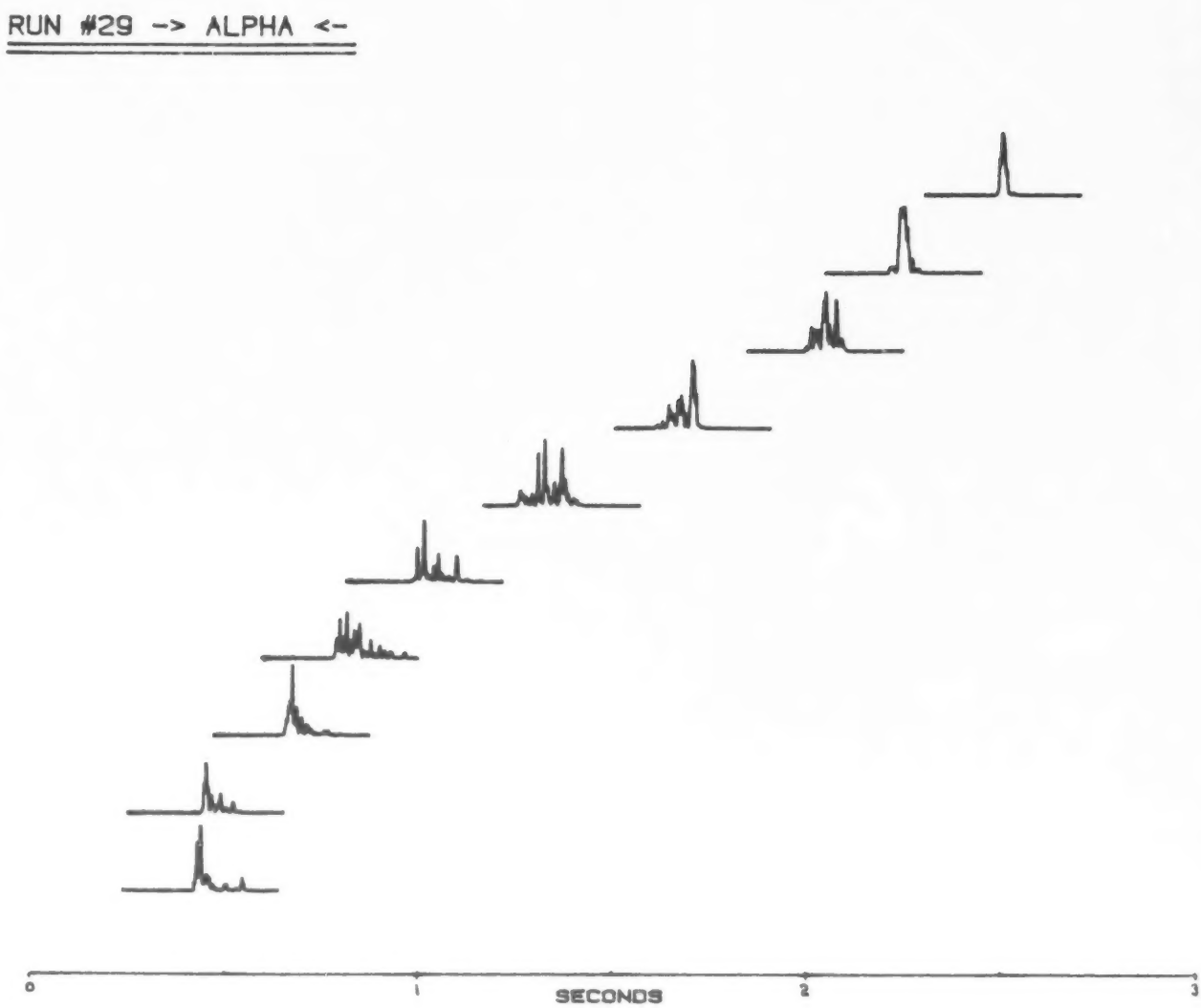


Figure A40 Iceberg #8, Run #29, Representative Echo Power Envelope

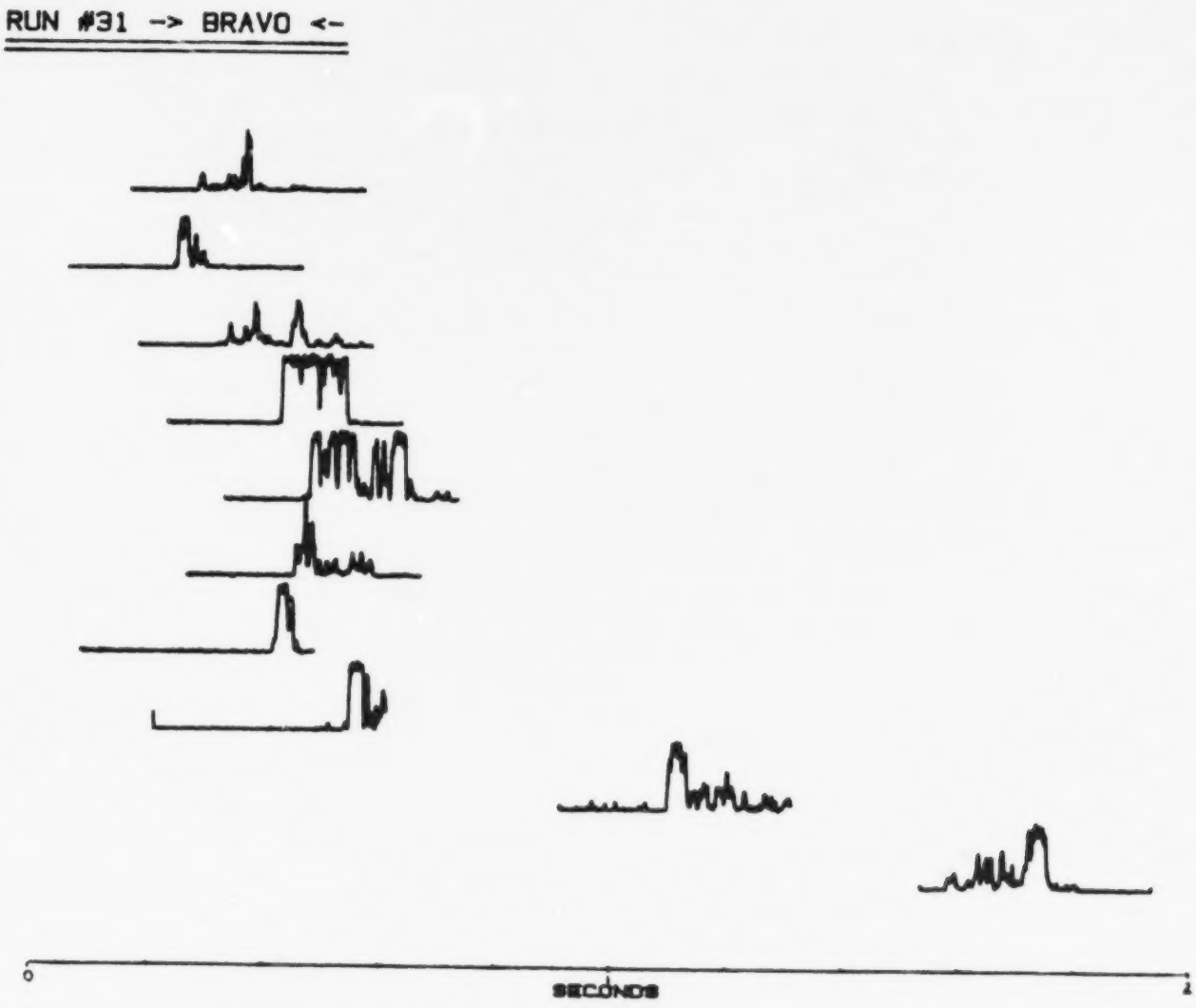
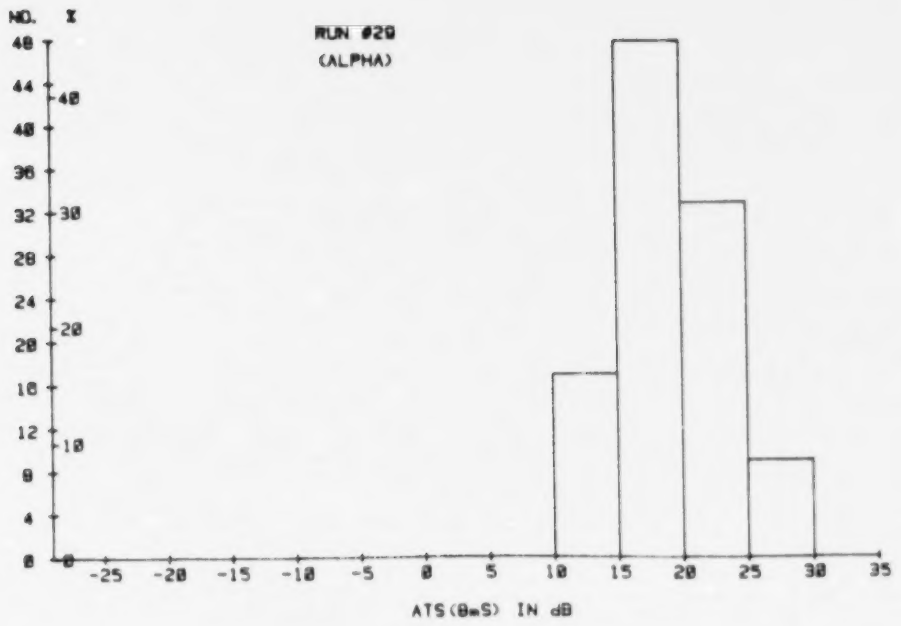


Figure A41 Iceberg #8, Run #31, Representative Echo Power Envelope



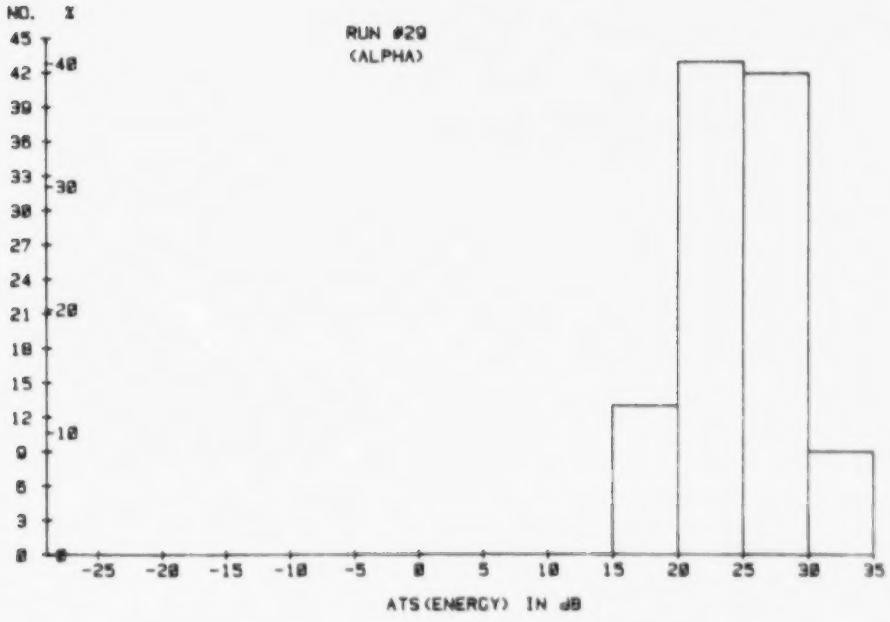
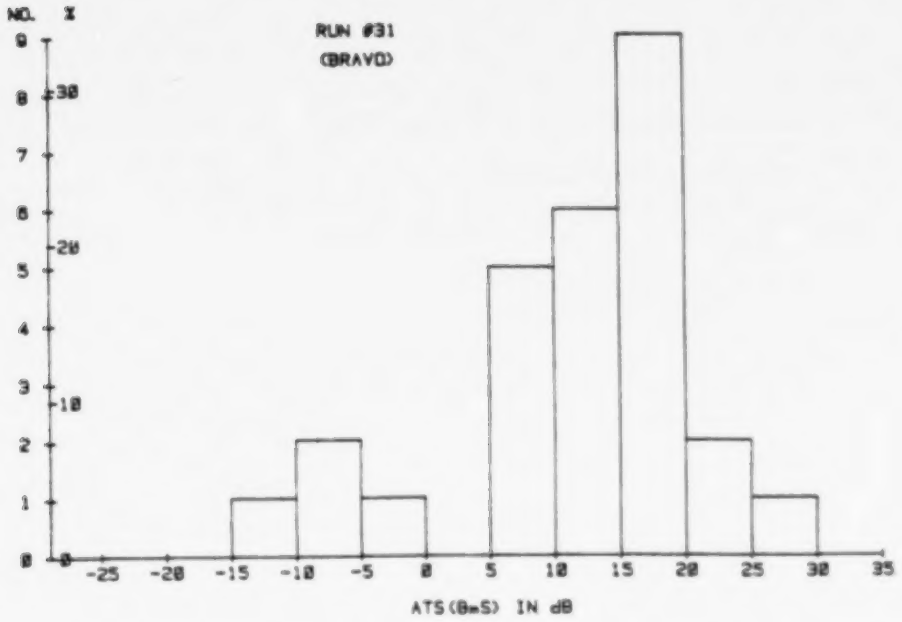


Figure 6.41

Figure A42 Iceberg #8, Run #29, Target Strength Statistics



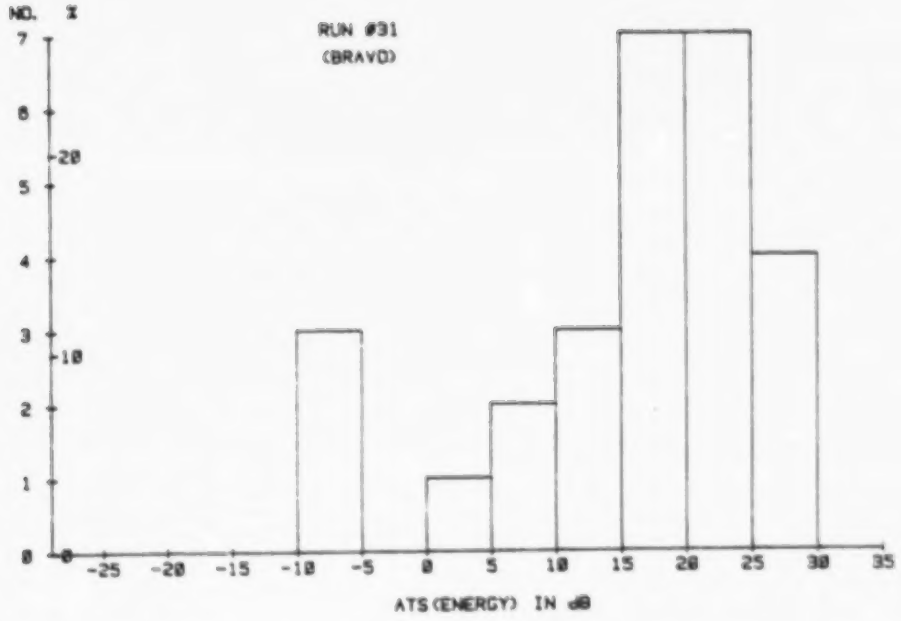
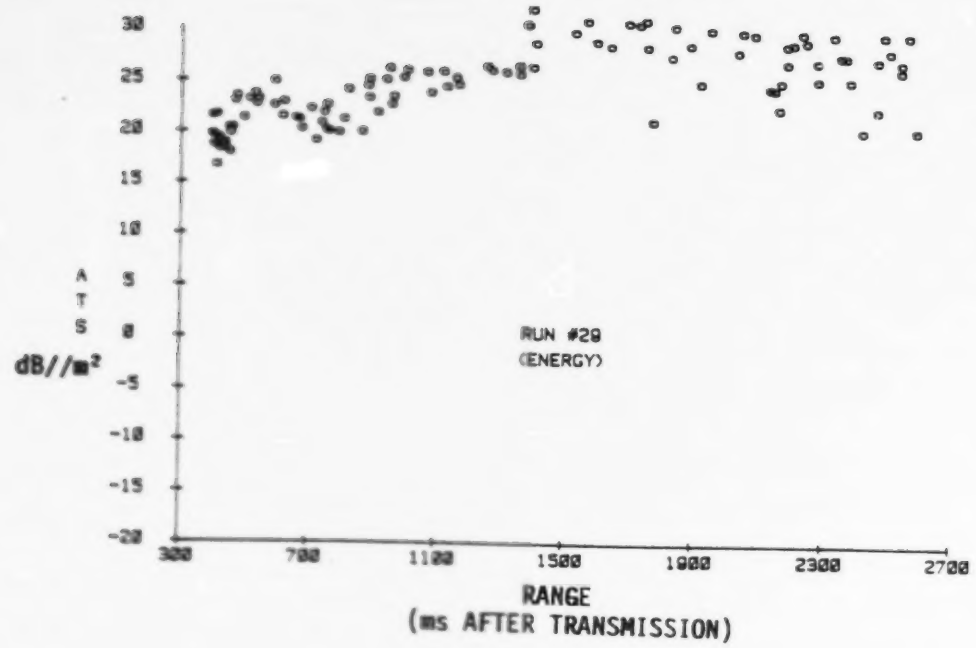


Figure A43 Iceberg #8, Run #3, Target Strength Statistics



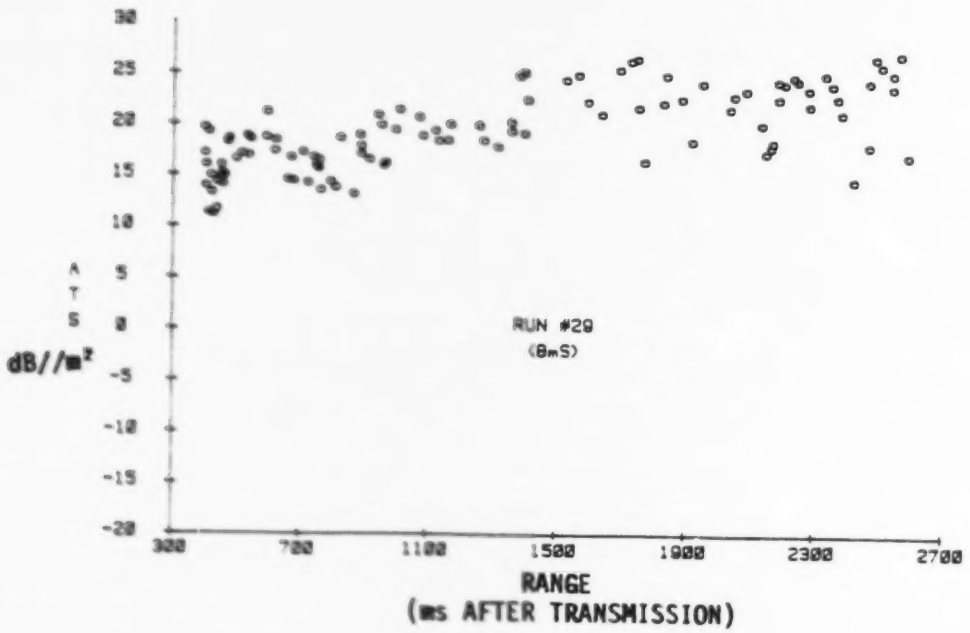


Figure A44 Iceberg #8, Run #29, Acoustic Target Strength

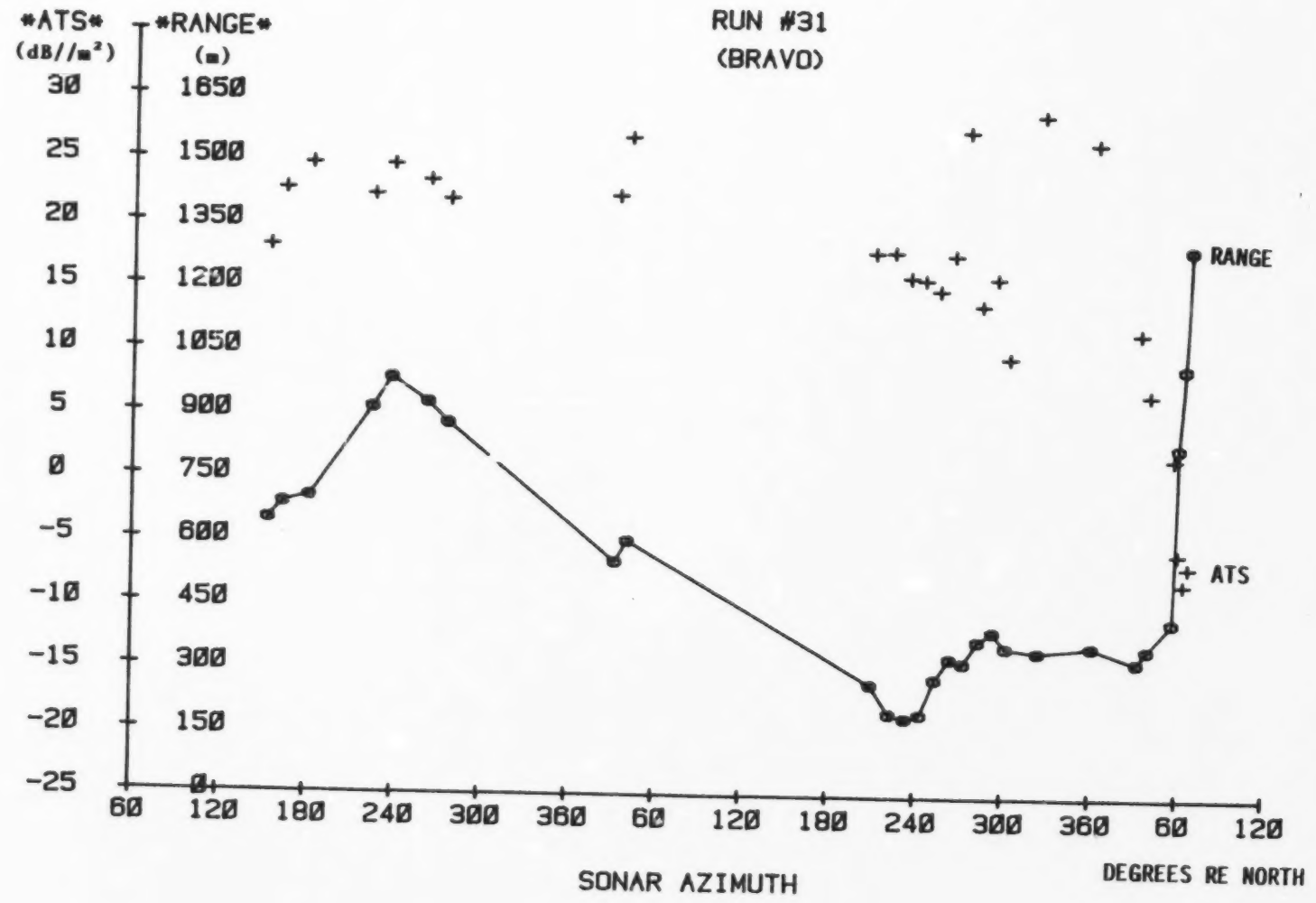


Figure A47 Iceberg #10, Run #31, Acoustic Target Strength and Range VS. Sonar Azimuth

DATA SUMMARY ICEBERG NO. 9

Sea State 2 Wind Speed 12 knots

Temperature 6°, very sunny Water Depth 400 m

Date	Run No.	Run Type	Comments
30 July	33	Alpha	2 of 7 readings used
30 July	34	Alpha	1 of 15 readings used (propagation limited)

ICEBERG DESCRIPTION

Height above waterline	11.9 m
Length at waterline	70 m
Estimated Draught	30 m
Iceberg Classification	Medium

TARGET STRENGTH MEASUREMENTS

Number of Estimates 3

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	6.67	10.14
Standard Deviation dB	6.25	5.98
Median dB	6.86	10.65
10th Percentile dB	12.82	15.84
90th Percentile dB	.32	3.92

ICEBERG #09

0 50m

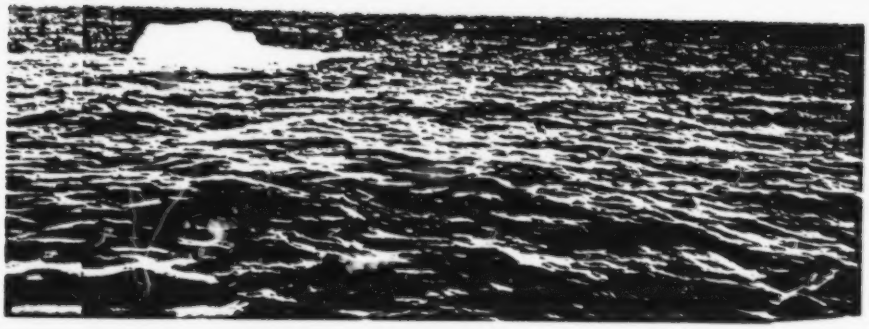


PLATE A9

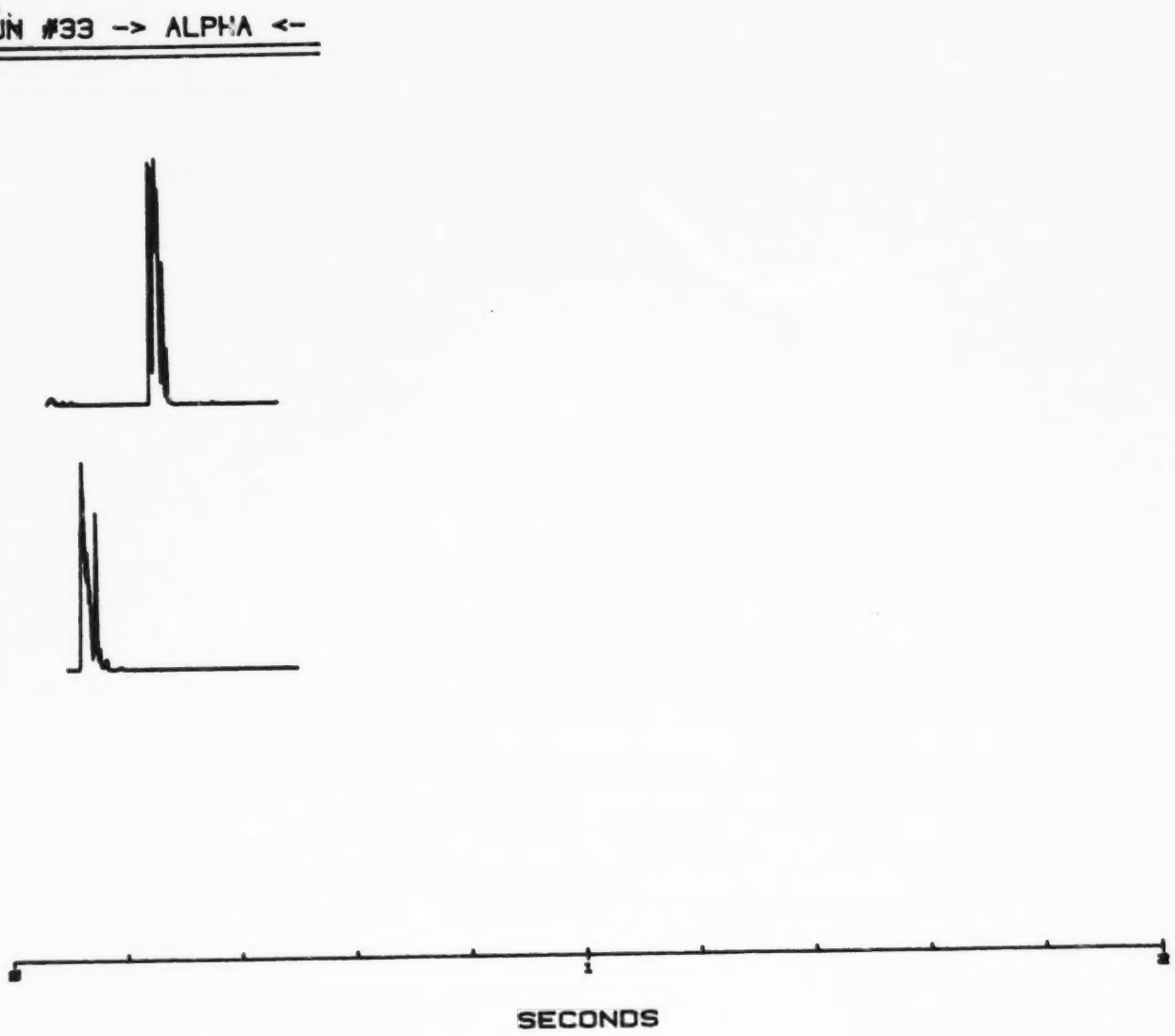


Figure A45 Iceberg #9, Run #33, Representative Echo Power Envelope

DATA SUMMARY ICEBERG NO. 10

Sea State 2 Wind Speed Not recorded

Temperature _____ Water Depth 500 m

Date	Run No.	Run Type	Comments
30 July	35	Alpha	Rejected (8 readings)
30 July	37	Alpha	7 of 10 used; lots of bubbles around berg

ICEBERG DESCRIPTION

Height above waterline 10.6 m
Length at waterline 39 m
Estimated Draught 30 m
Iceberg Classification Small berg, pinnacled in advanced disintegration

TARGET STRENGTH MEASUREMENTS

Number of Estimates 7

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	- 5.06	- 1.55
Standard Deviation dB	11.69	12.68
Median dB	- 4.6	- 1.4
10th Percentile dB	6.66	9.92
90th Percentile dB	-20.27	-18.06

ICEBERG #10

0 40m

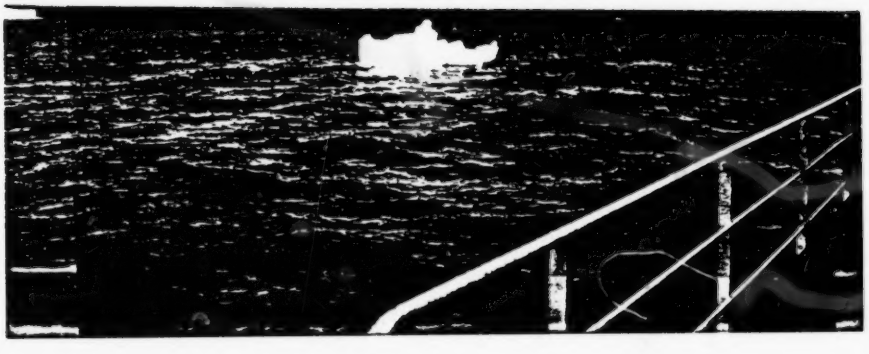


PLATE A10

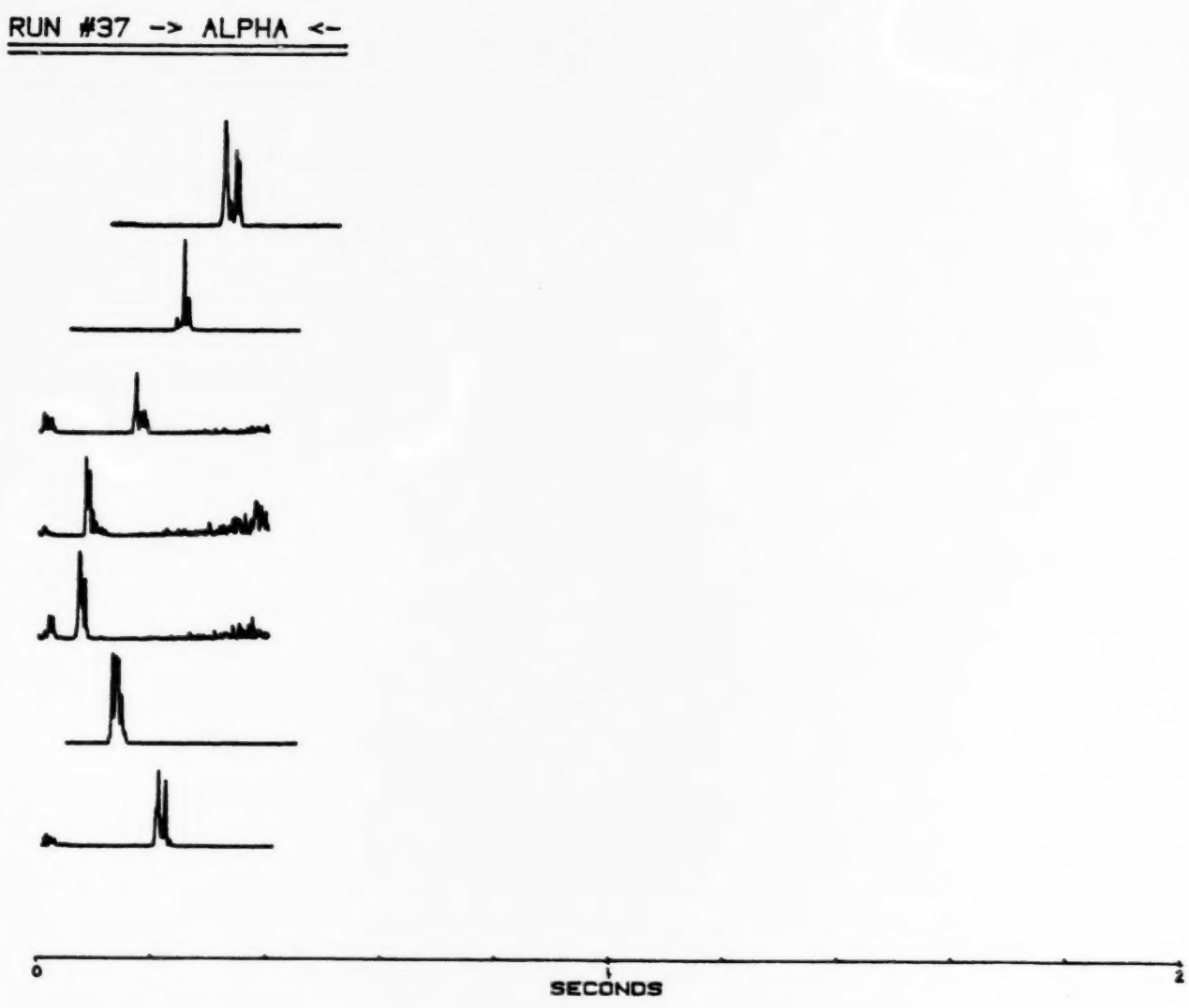


Figure A46 Iceberg #10, Run #37, Representative Echo Power Envelope

DATA SUMMARY ICEBERG NO. 11

Sea State: Very calm

Wind Speed: Not recorded

Temperature:

Water Depth: 500 m

Date	Run No.	Run Type	Comments
30 July	38	Alpha	11 of 31 readings used
30 July	39	Charlie/Bravo	23 of 30 readings used

ICEBERG DESCRIPTION

Height above waterline: 31 m

Length at waterline: 120 m

Estimated Draught: 90 m

Iceberg Classification: Medium berg, domed, smooth, probably turned over

TARGET STRENGTH MEASUREMENTS

Number of Estimates: 34

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	2.67	7.94
Standard Deviation dB	9.05	9.0
Median dB	3.72	8.37
10th Percentile dB	14.48	18.19
90th Percentile dB	- 9.08	- 6.04

ICEBERG #11

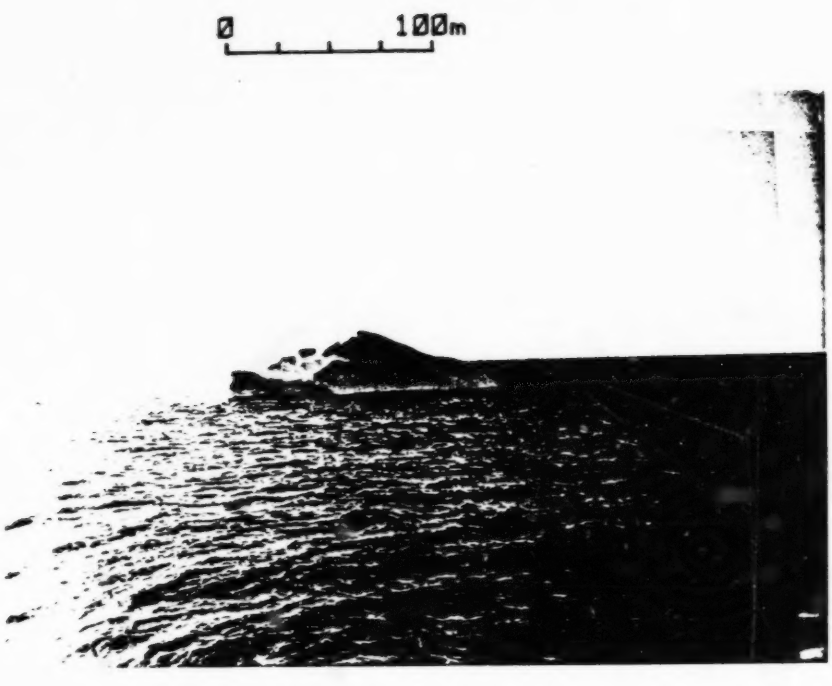


PLATE A11

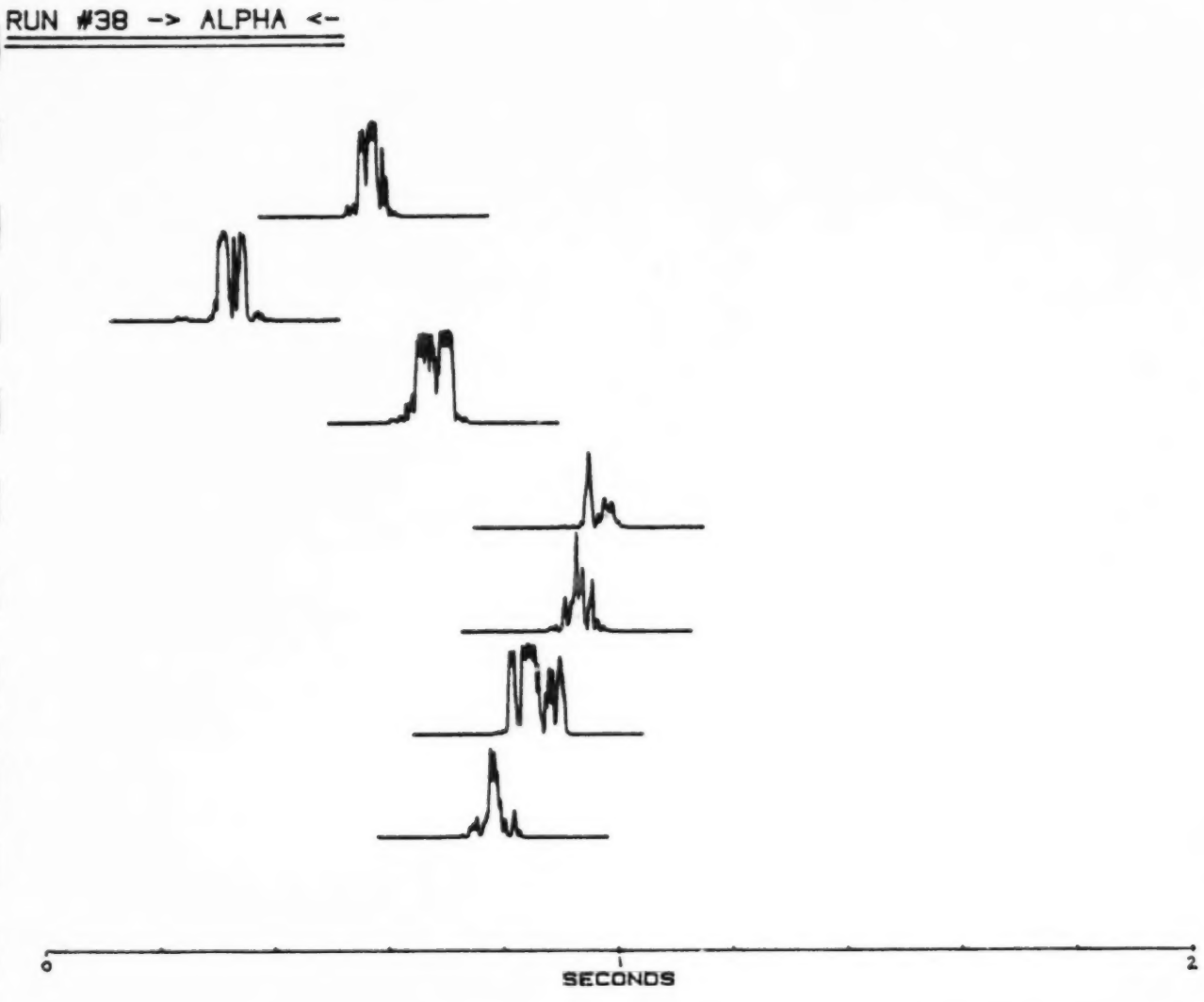


Figure A48 Iceberg #11, Run #38, Representative Echo Power Envelope

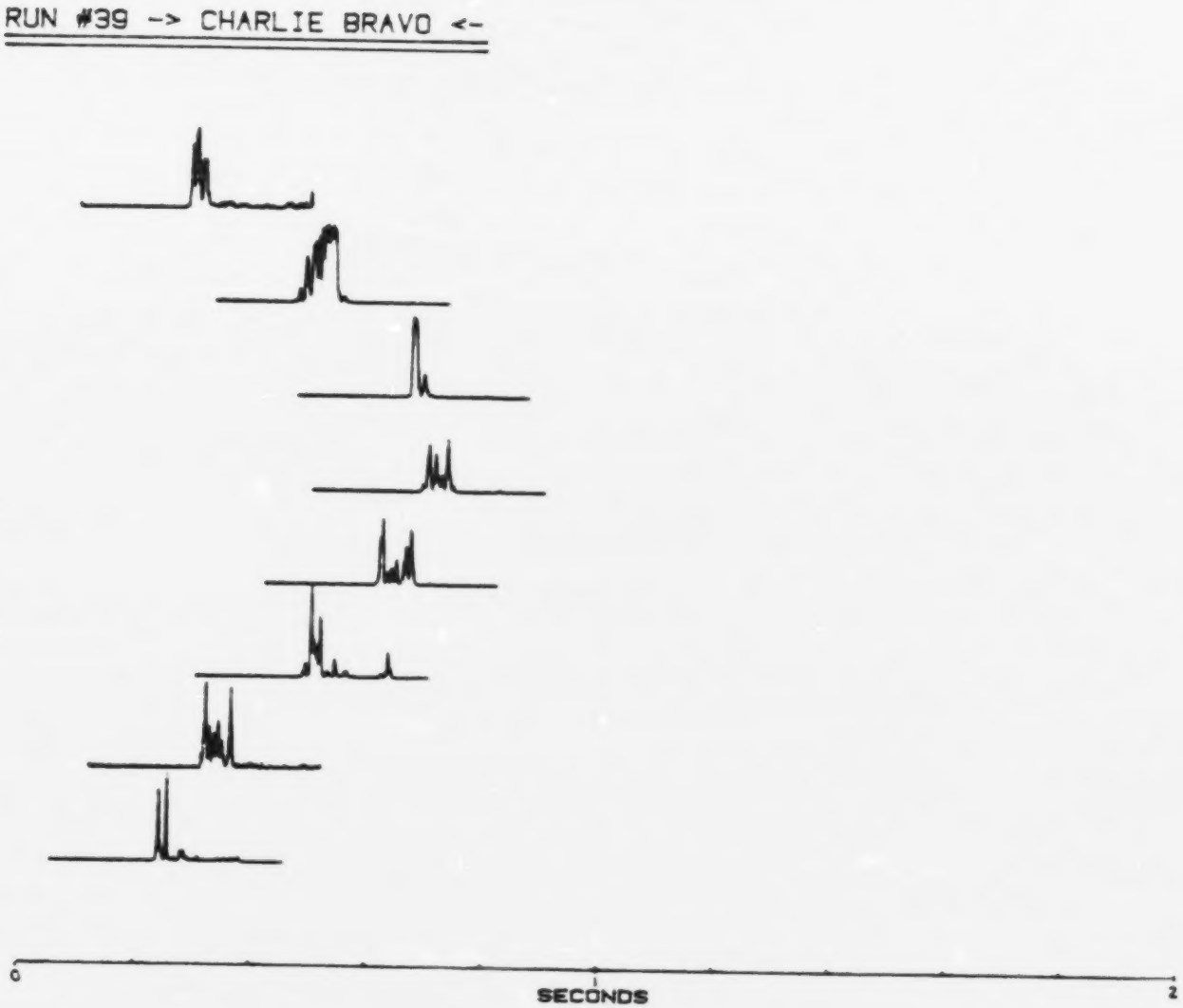
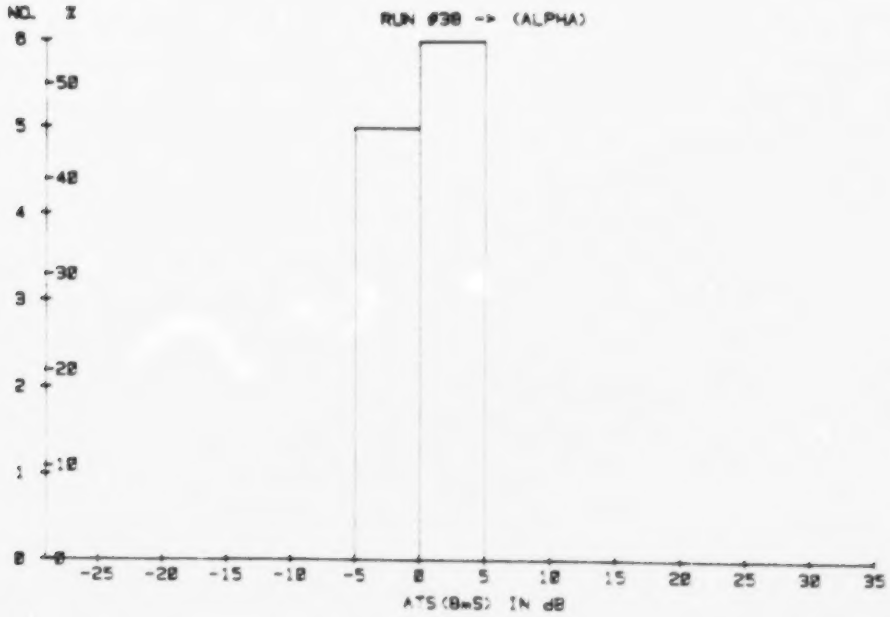


Figure A49 Iceberg #11, Run #39, Representative Echo Power Envelope



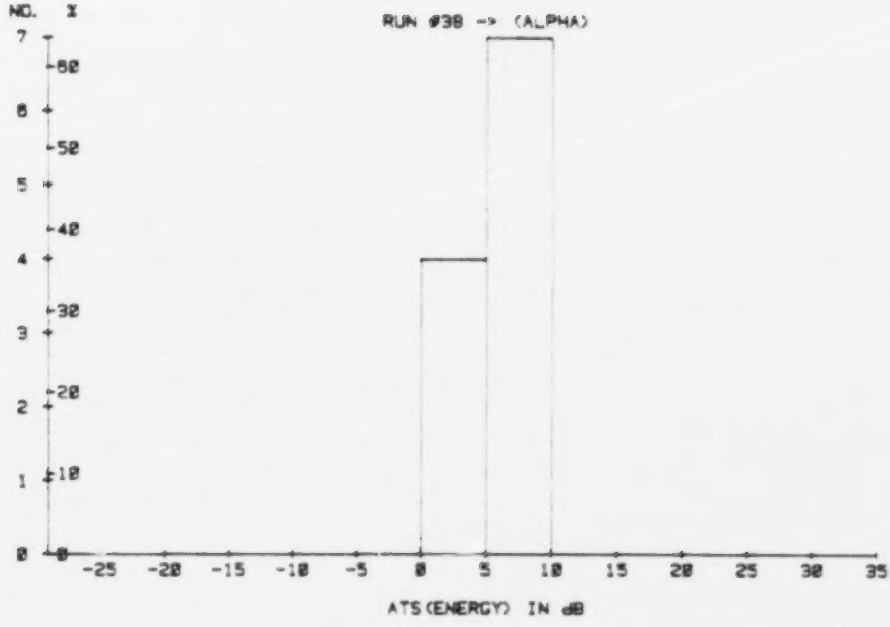
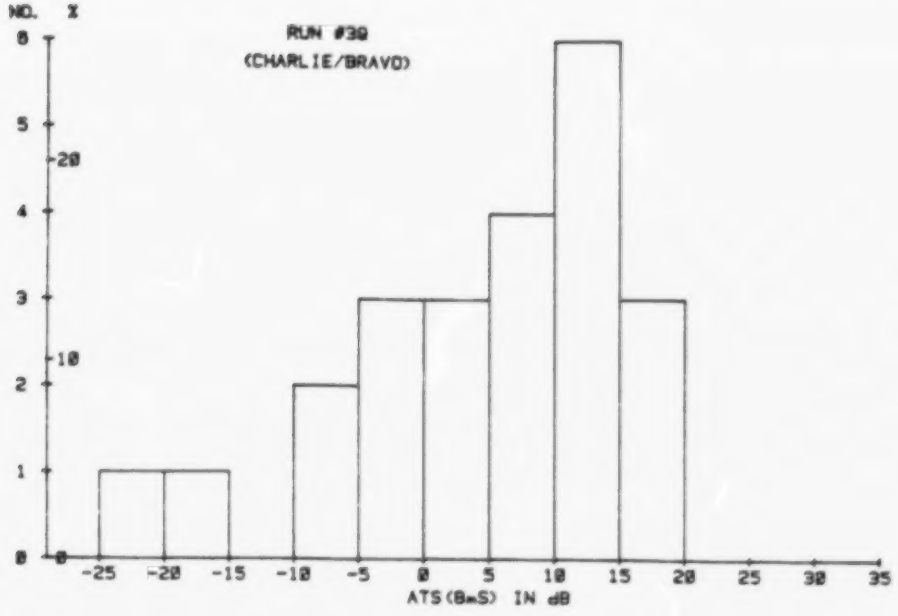


Figure A50 Iceberg #11, Run #38, Target Strength Statistics



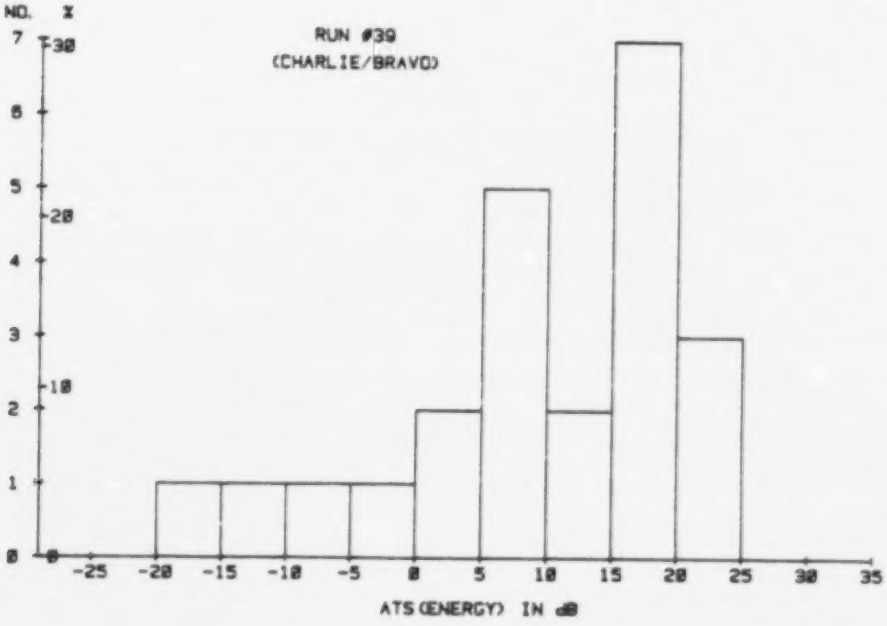
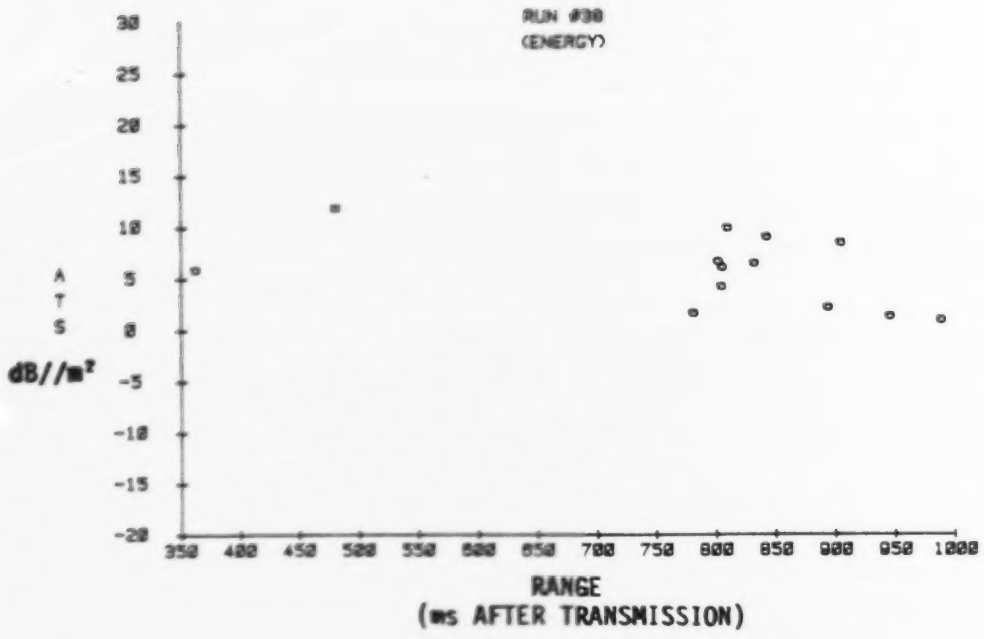


Figure A51 Iceberg #11, Run #39, Target Strength Statistics



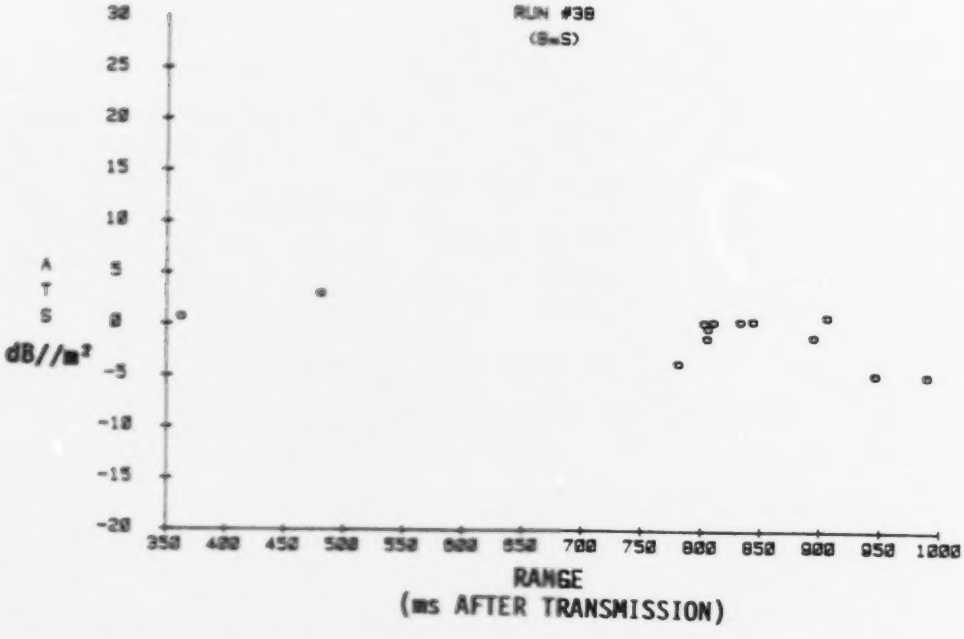


Figure A52 Iceberg #11, Run #38, Acoustic Target Strength

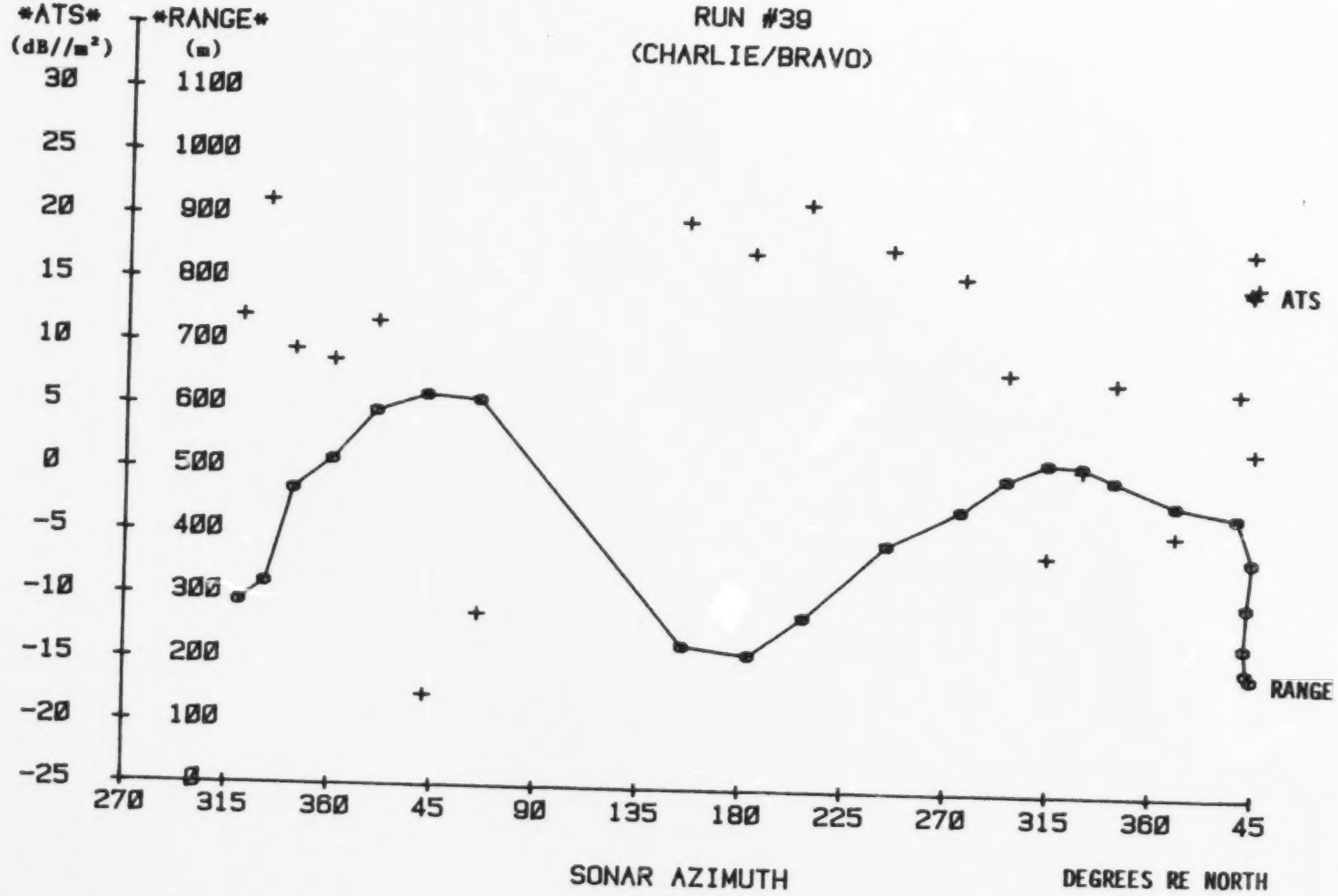


Figure A53 Iceberg #11, Run #39, Acoustic Target Strength and Range VS. Sonar Azimuth

DATA SUMMARY ICEBERG NO. 12

Sea State Calm Wind Speed Not recorded

Temperature _____ Water Depth 500 m

Date	Run No.	Run Type	Comments
30 July	40	Charlie	3 of 16 readings used
30 July	41	Charlie	Rejected - no echoes

Note: Two other growlers, about 1 m freeboard x 2 or 3 m length, were not detected, probably due to propagation conditions coupled to shading by ship's hull.

ICEBERG DESCRIPTION

Height above waterline 1.5 m
Length at waterline 4 m
Estimated Draught 4.5 m
Iceberg Classification Growler

TARGET STRENGTH MEASUREMENTS

Number of Estimates 3

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	-18.27	-12.92
Standard Deviation dB	2.32	3.79
Median dB	-18.36	-12.39
10th Percentile dB	-15.9	-12.21
90th Percentile dB	-20.54	-14.15

ICEBERG #12

Ø 10m

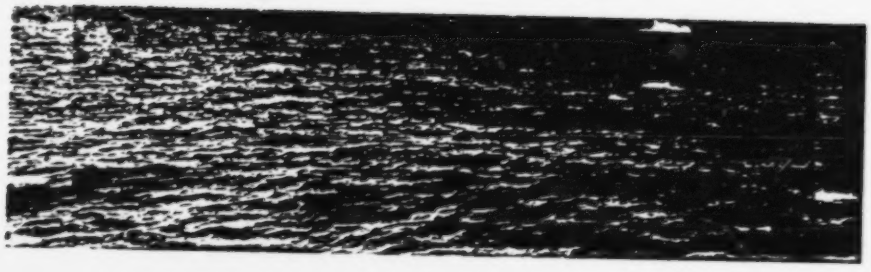


PLATE A12

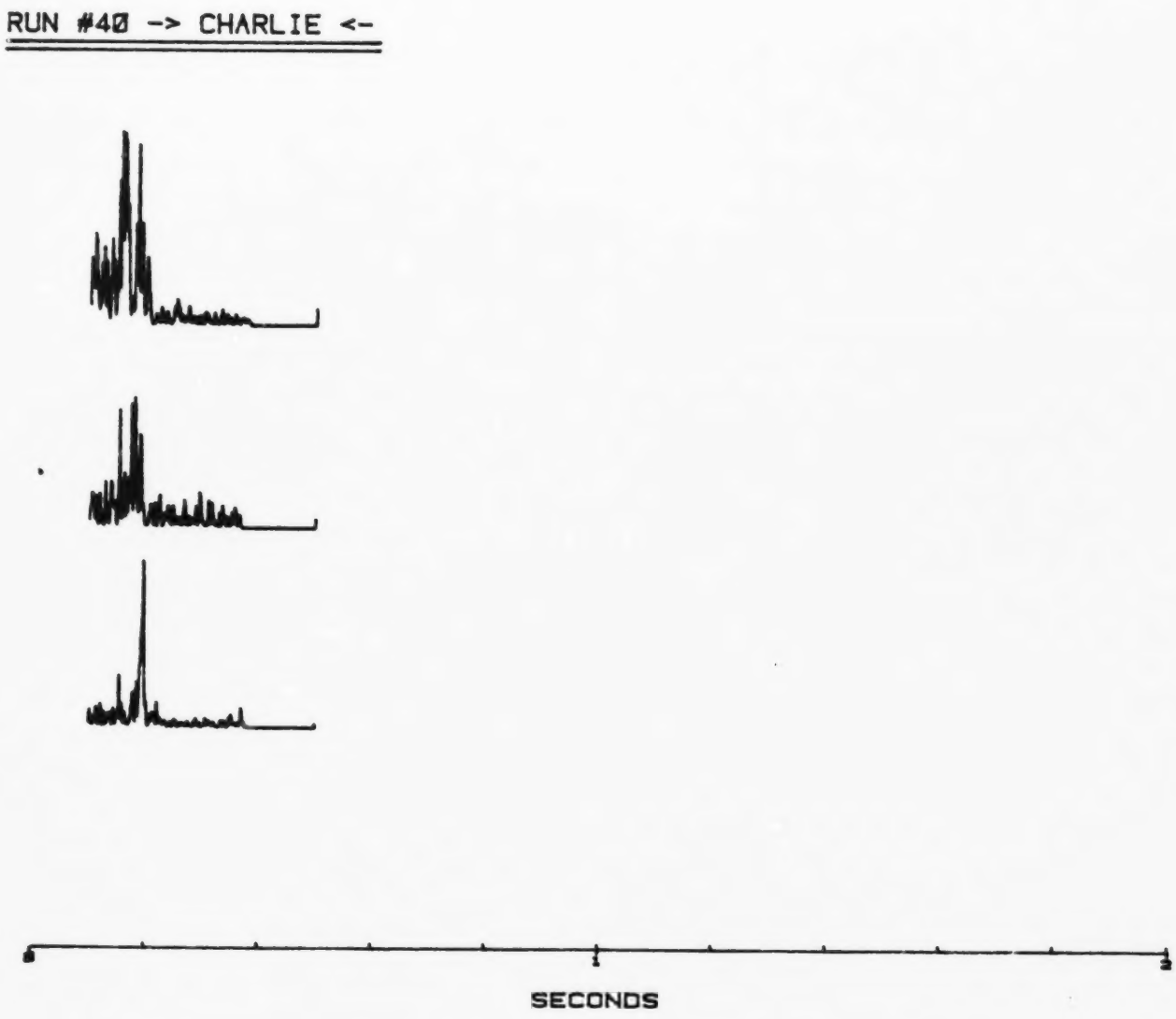


Figure A54 Iceberg #12, Run #40, Representative Echo Power Envelope

DATA SUMMARY ICEBERG NO. 13

Sea State Calm Wind Speed Low

Temperature _____ Water Depth 500 m

Date	Run No.	Run Type	Comments
31 July	42	Alpha	4 of 9 readings used
31 July	43	Charlie	8 of 8 readings used

ICEBERG DESCRIPTION

Height above waterline	13 m
Length at waterline	67 m
Estimated Draught	30 m
Iceberg Classification	Medium

TARGET STRENGTH MEASUREMENTS

Number of Estimates 12

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	- 3.58	1.47
Standard Deviation dB	11.56	12.17
Median dB	- 3.75	2.2
10th Percentile dB	11.35	14.28
90th Percentile dB	-24.77	-21.61

ICEBERG #13

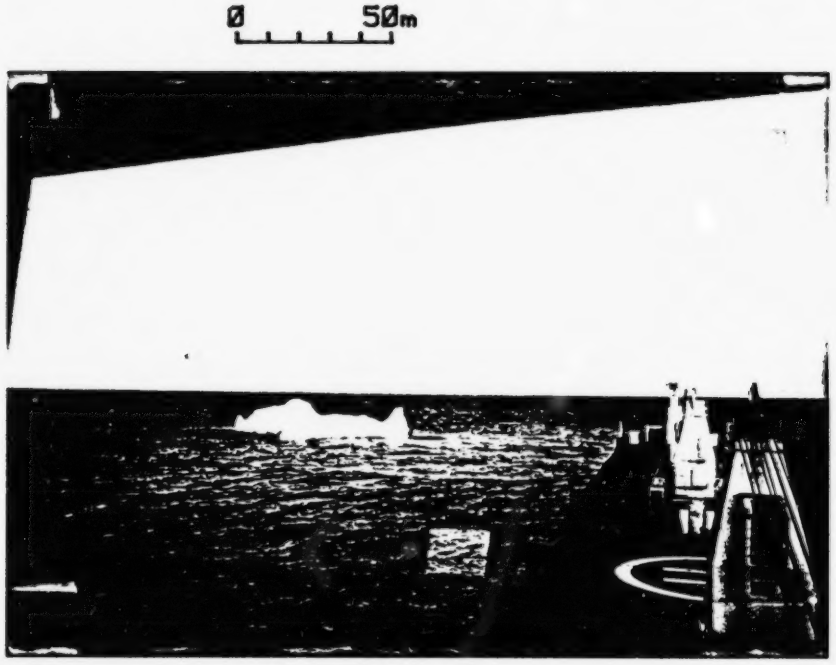


PLATE A13

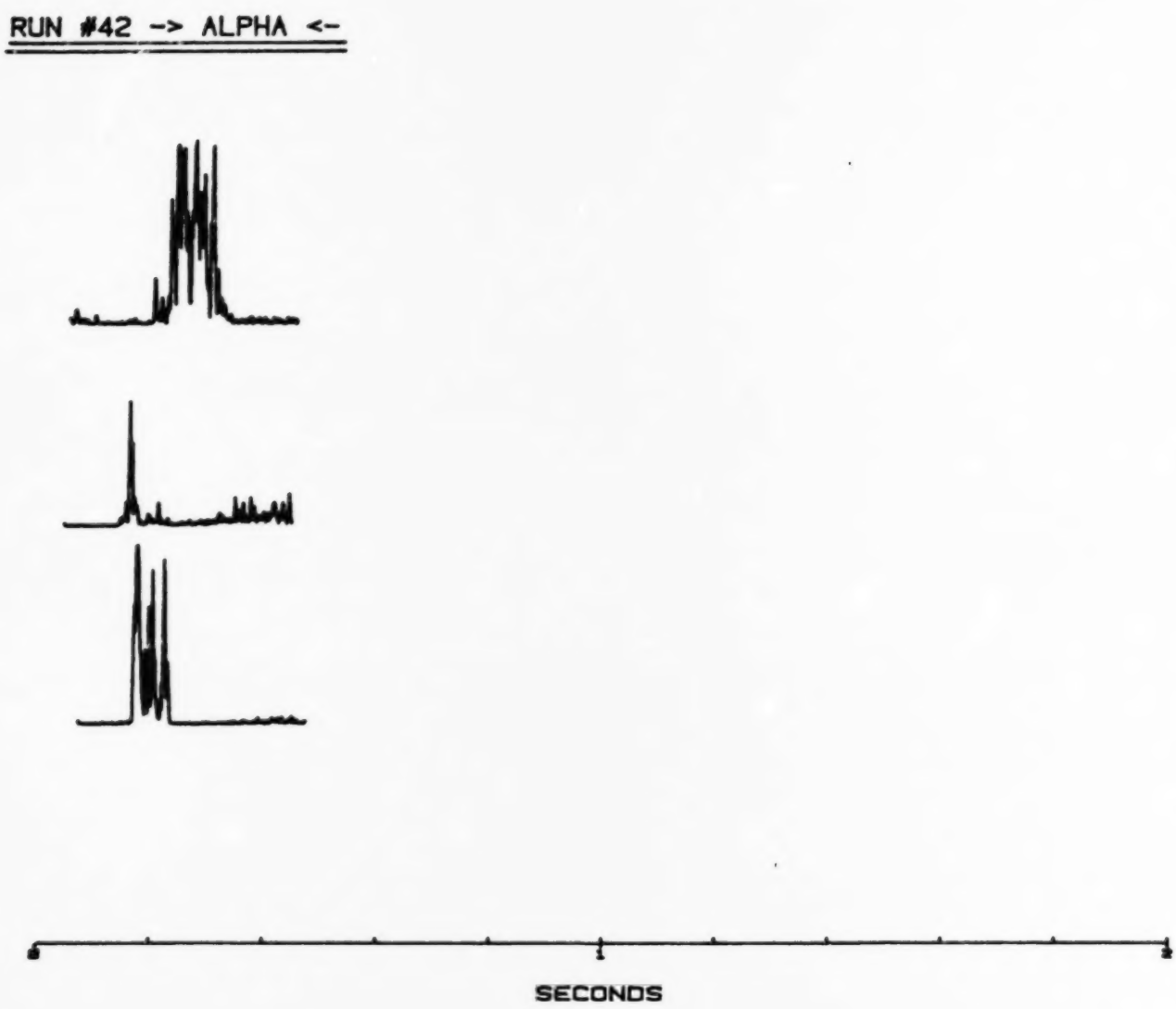


Figure A55 Iceberg #13, Run #42, Representative Echo Power Envelope

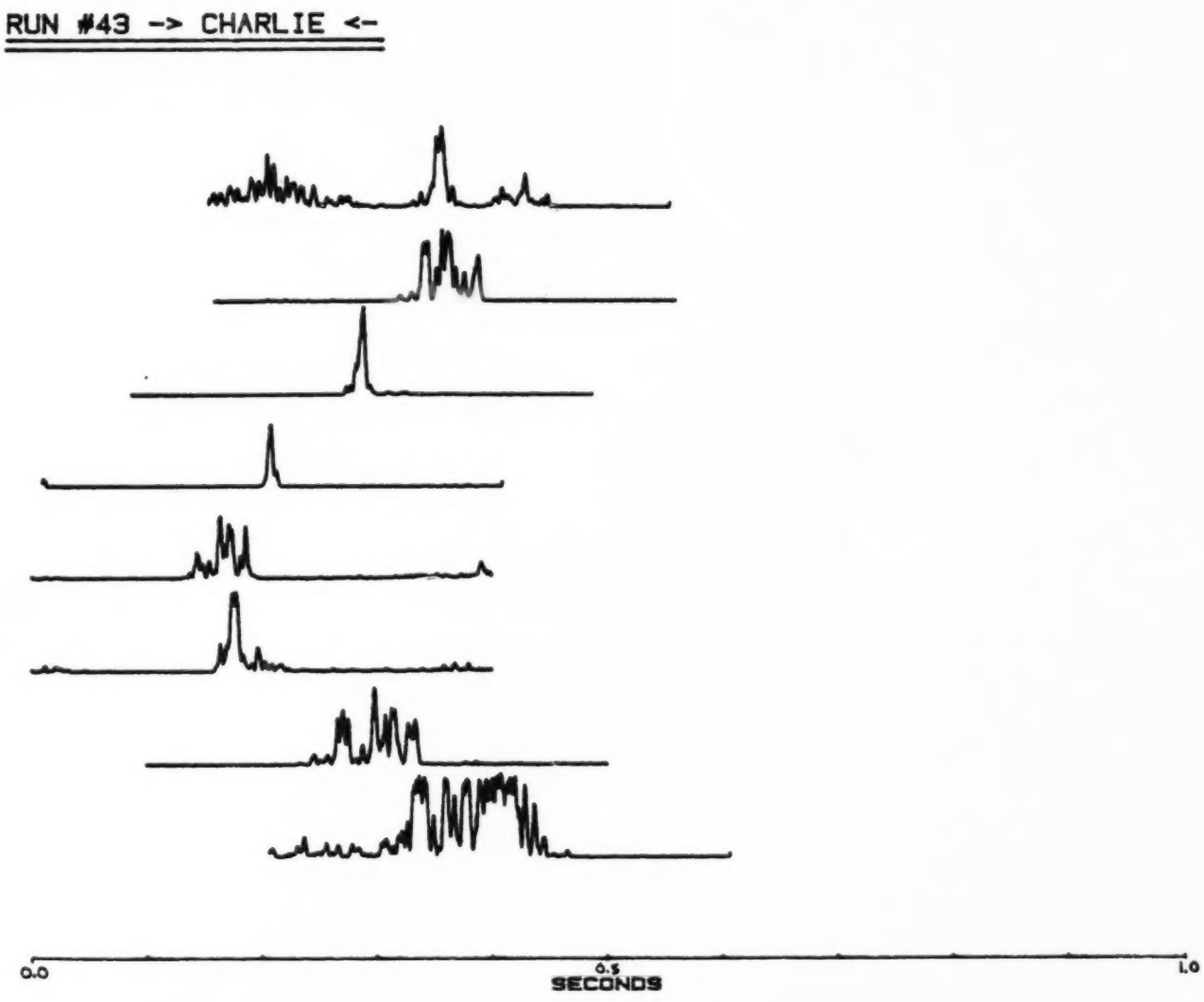
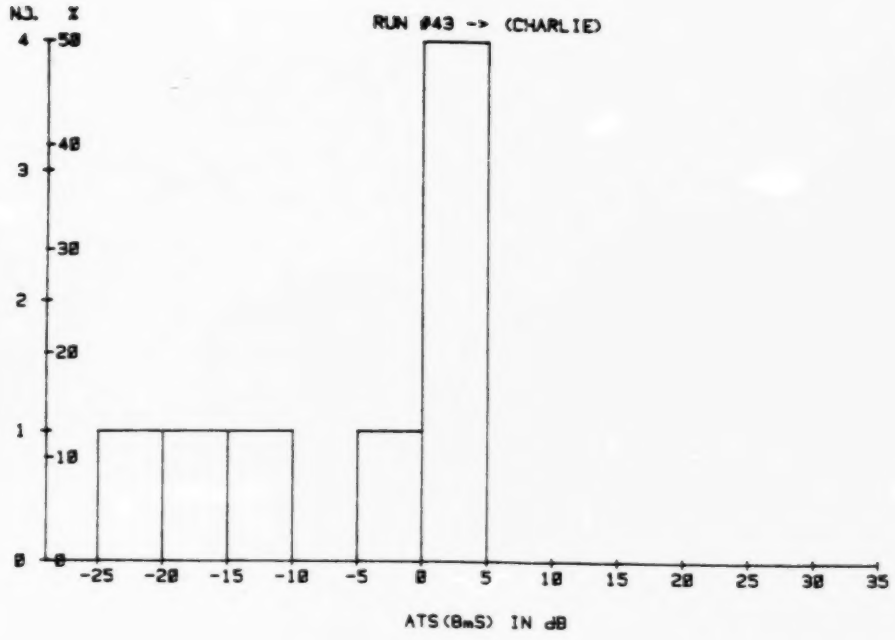


Figure A56 Iceberg #13, Run #43, Representative Echo Power Envelope



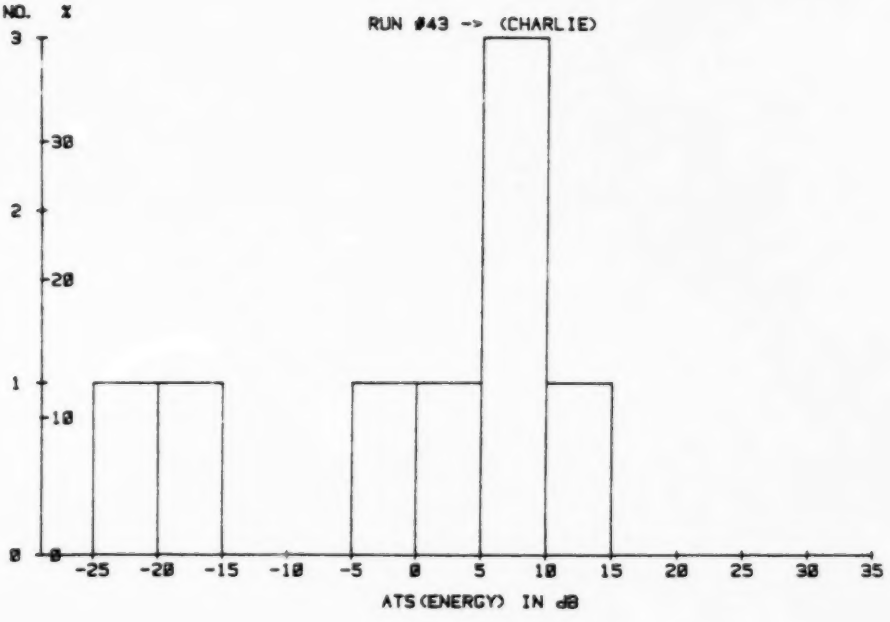
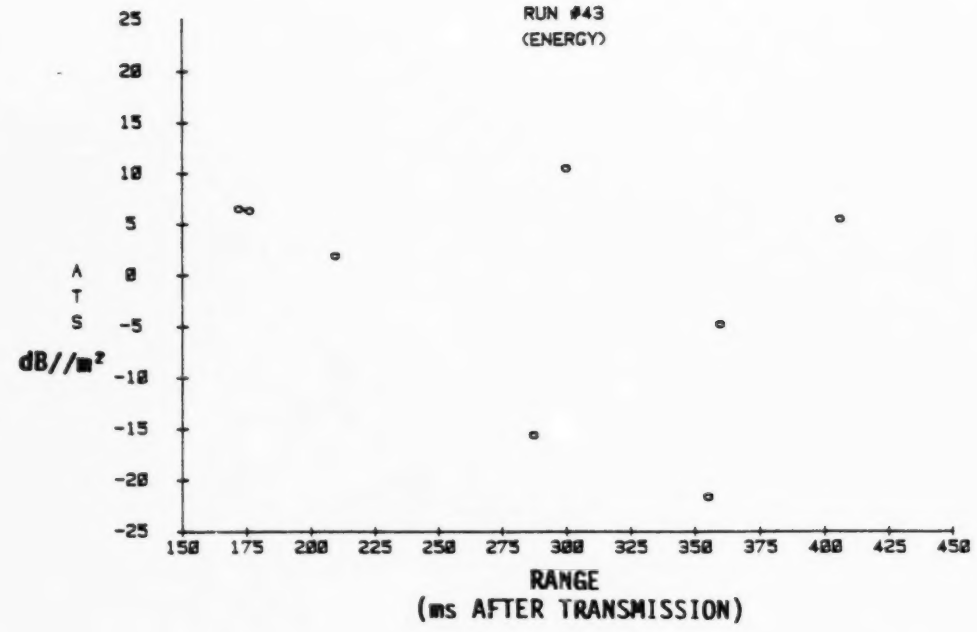


Figure A57 Iceberg #13, Run #43, Target Strength Statistics



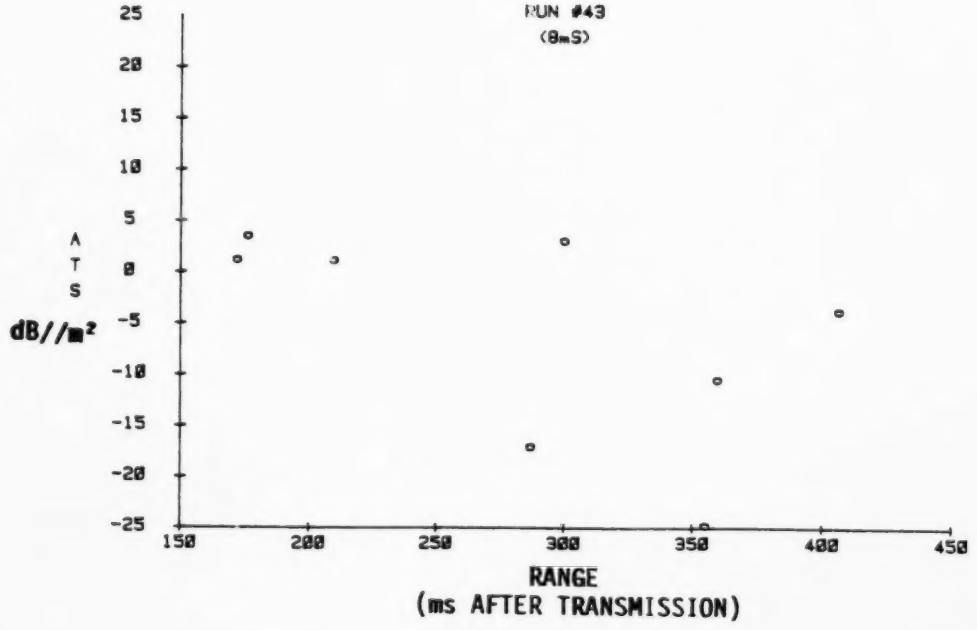


Figure A58 Iceberg #13, Run #43, Acoustic Target Strength

DATA SUMMARY ICEBERG NO. 14

Sea State Calm

Wind Speed Low

Temperature

Water Depth 500 m

Date	Run No.	Run Type	Comments
31 July	44	Charlie	4 of 8 readings used
31 July	45	Charlie	46 of 50 readings used

ICEBERG DESCRIPTION

Height above waterline 5.5 m

Length at waterline 32 m

Estimated Draught 15 m

Iceberg Classification Small berg, smooth, weathered, almost domed. "Technically a growler, but can be classified as a small berg."

TARGET STRENGTH MEASUREMENTS

Number of Estimates 50

PARAMETER	PEAK VALUE (8 ms)	TOTAL ENERGY
Average Target Strength dB	- 8.57	- 5.52
Standard Deviation dB	6.94	6.77
Median dB	- 9.2	- 6.18
10th Percentile dB	- 1.39	- 1.37
90th Percentile dB	-15.36	-12.87

ICEBERG #14

0 20m

PLATE A14

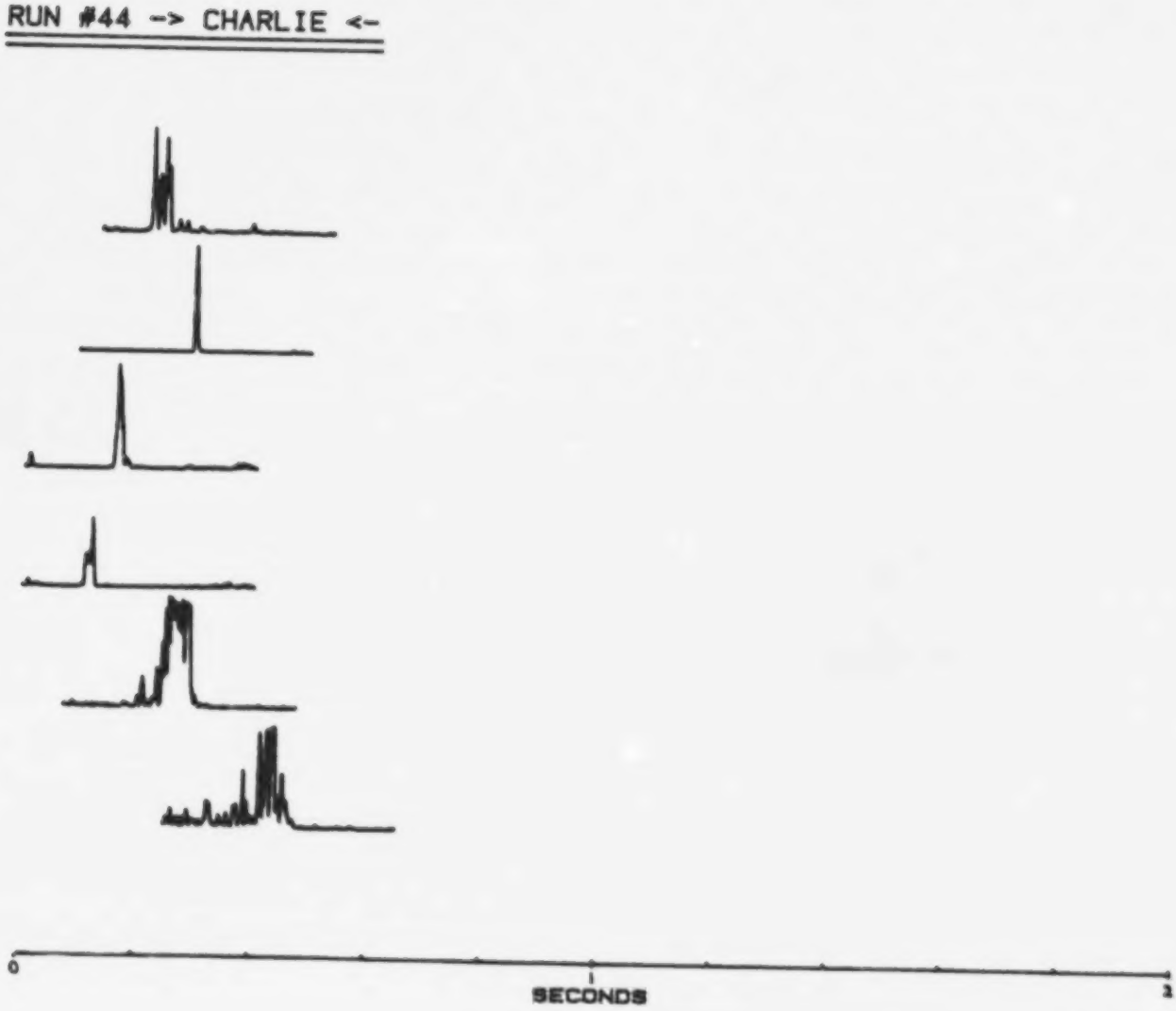


Figure A59 Iceberg #14, Run #44, Representative Echo Power Envelope

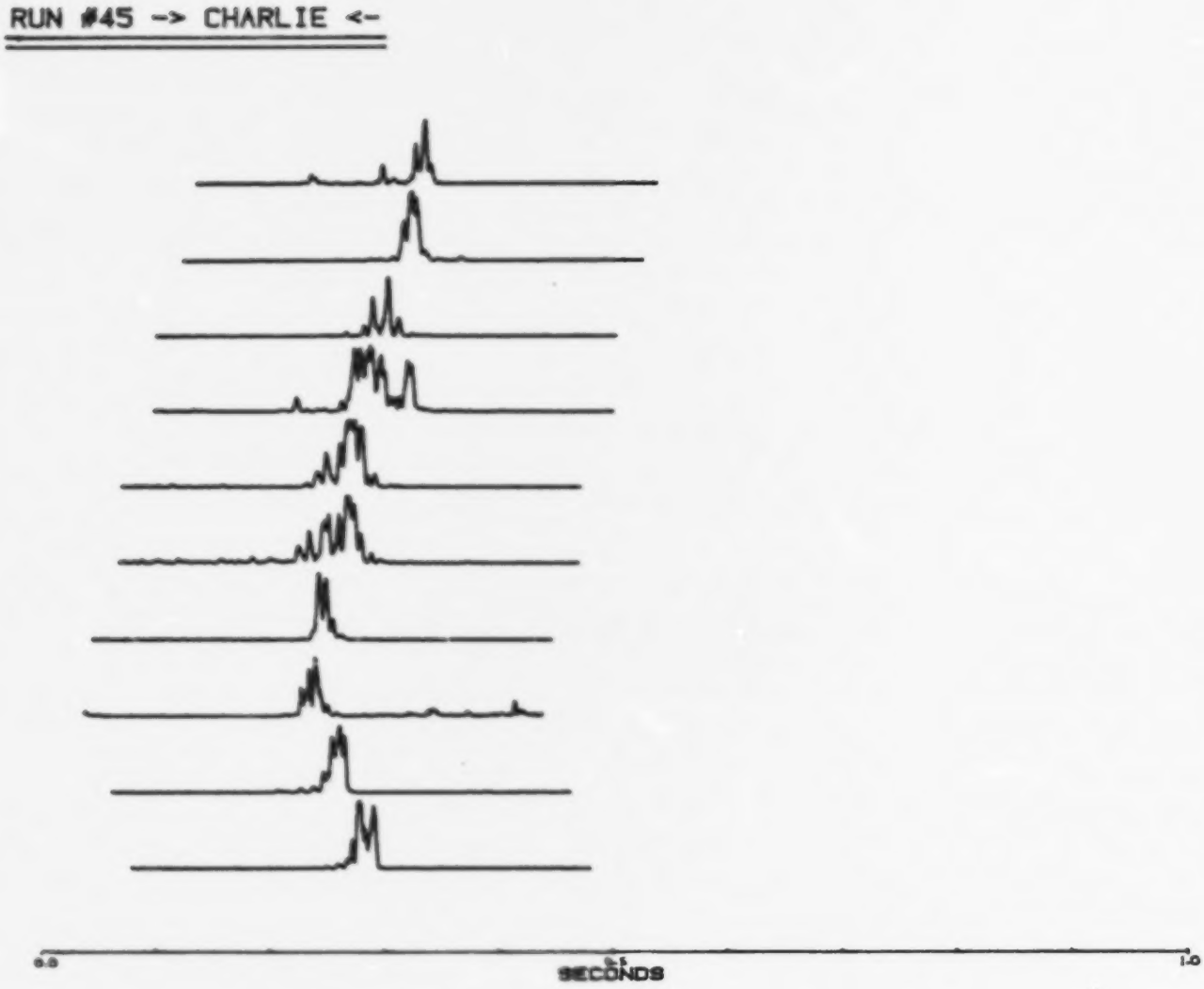
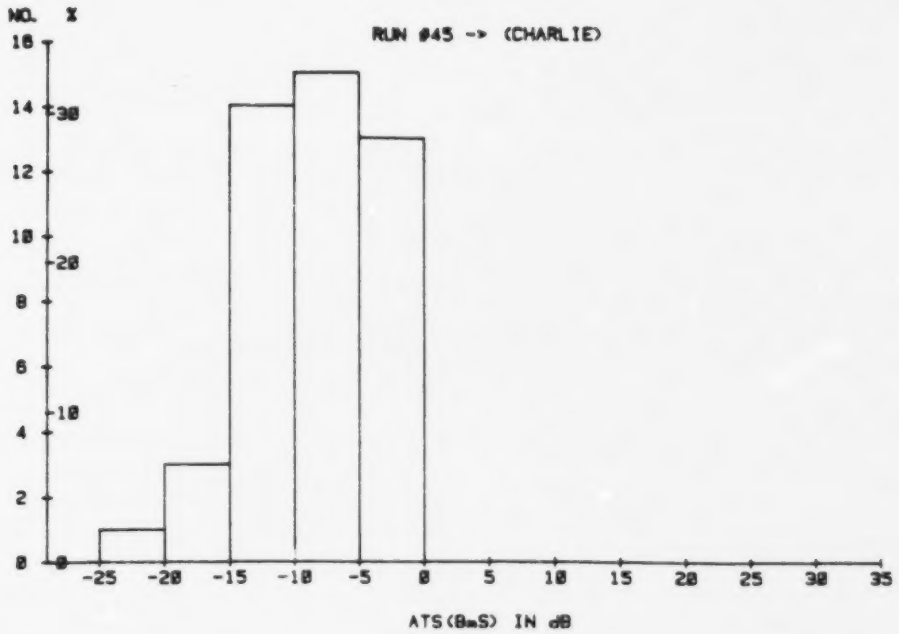


Figure A60 Iceberg #14, Run #45, Representative Echo Power Envelope



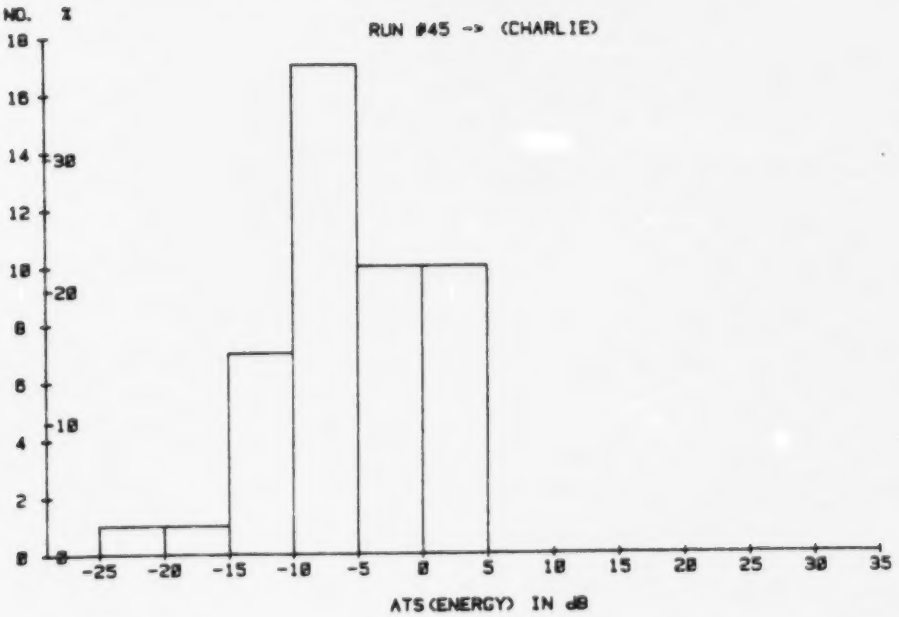
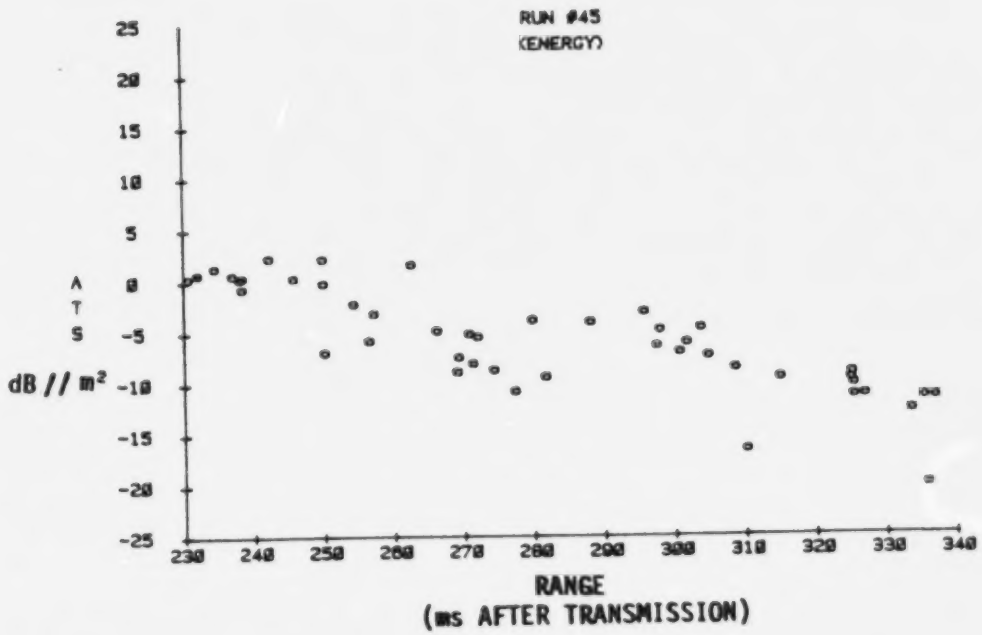


Figure A61 Iceberg #14, Run #45, Target Strength Statistics



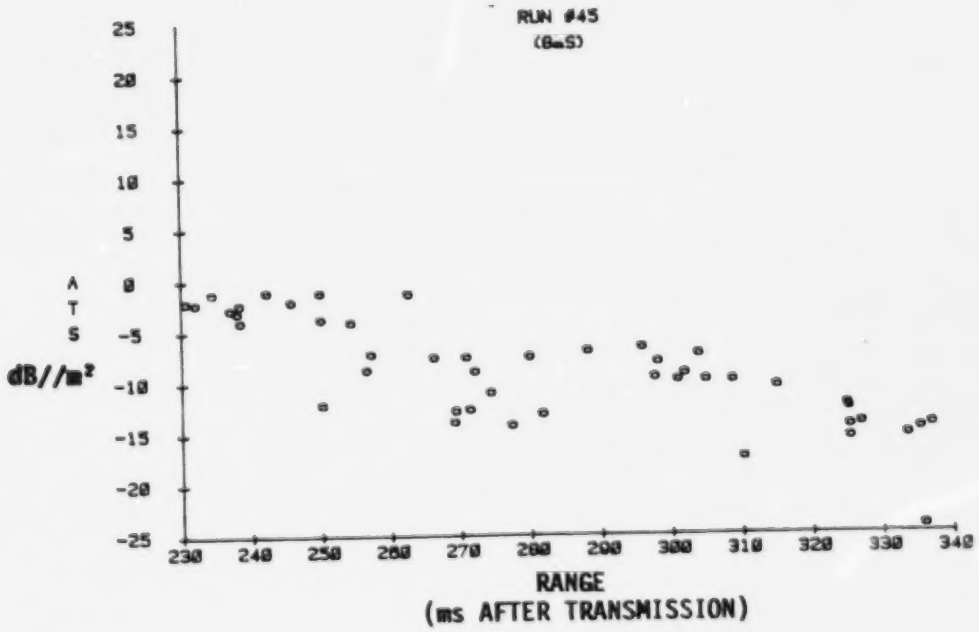
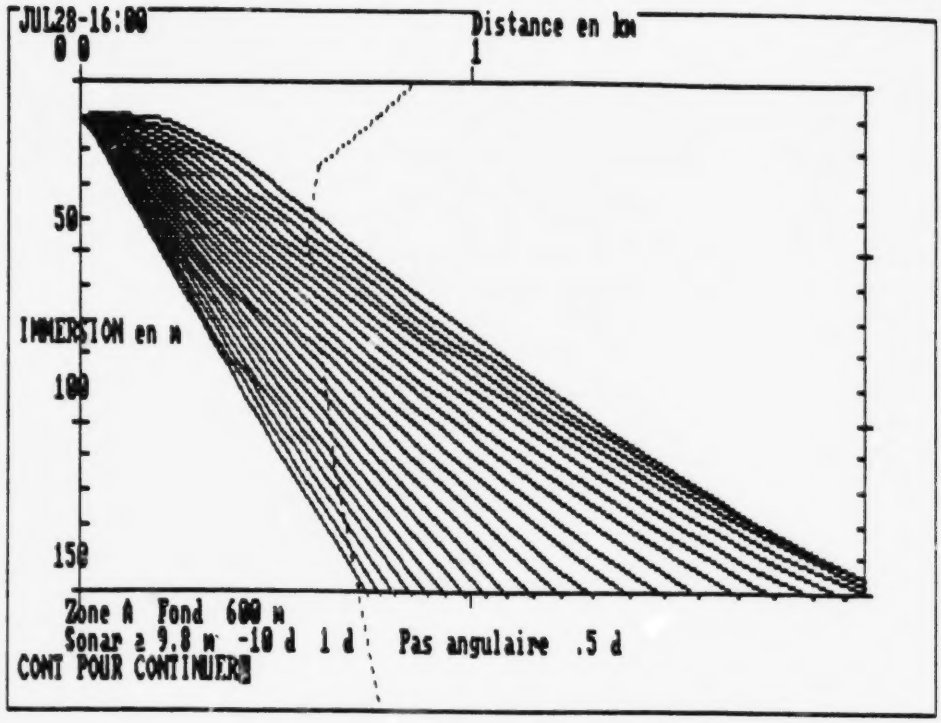


Figure A62 Iceberg #14, Run #45, Acoustic Target Strength

APPENDIX VI

MEASURED SOUND SPEED PROFILES AND RAY-TRACE DIAGRAMS



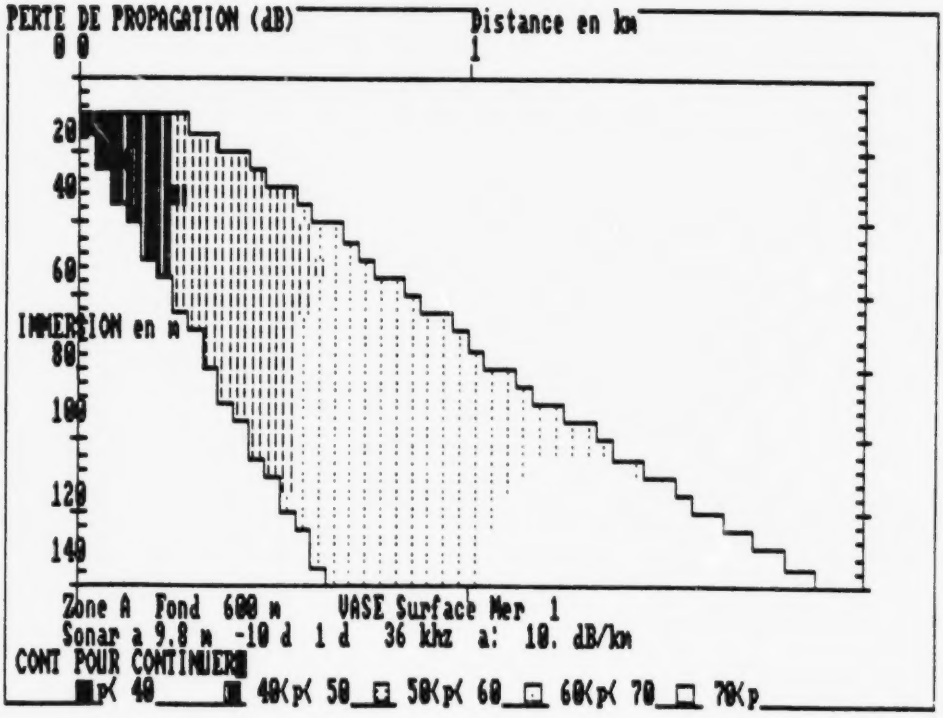
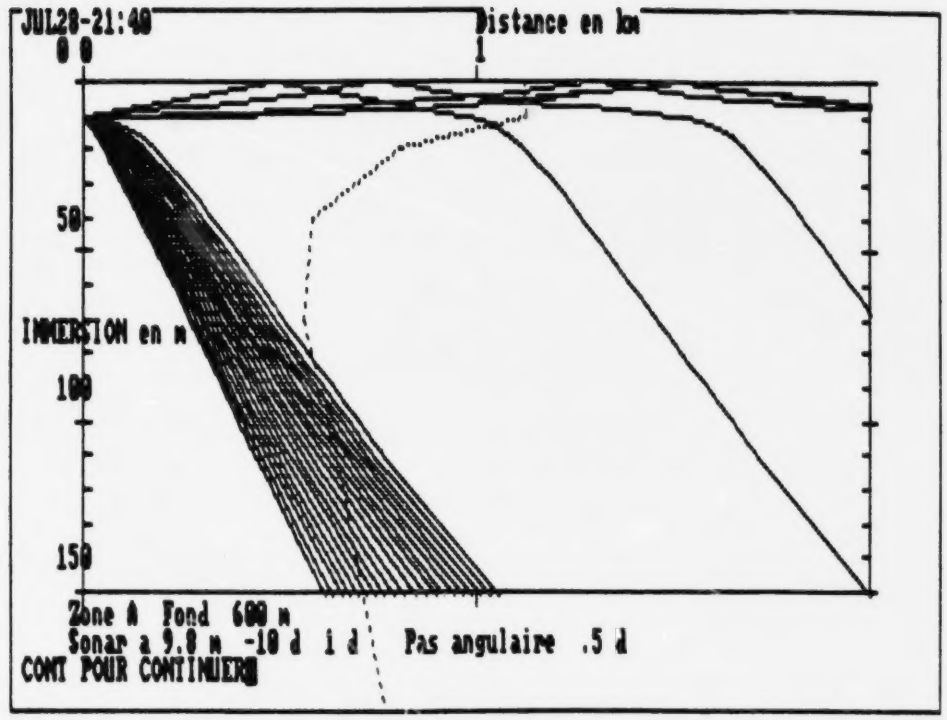


Figure A63 Estimated Propagation on July 28, 16:00 GMT



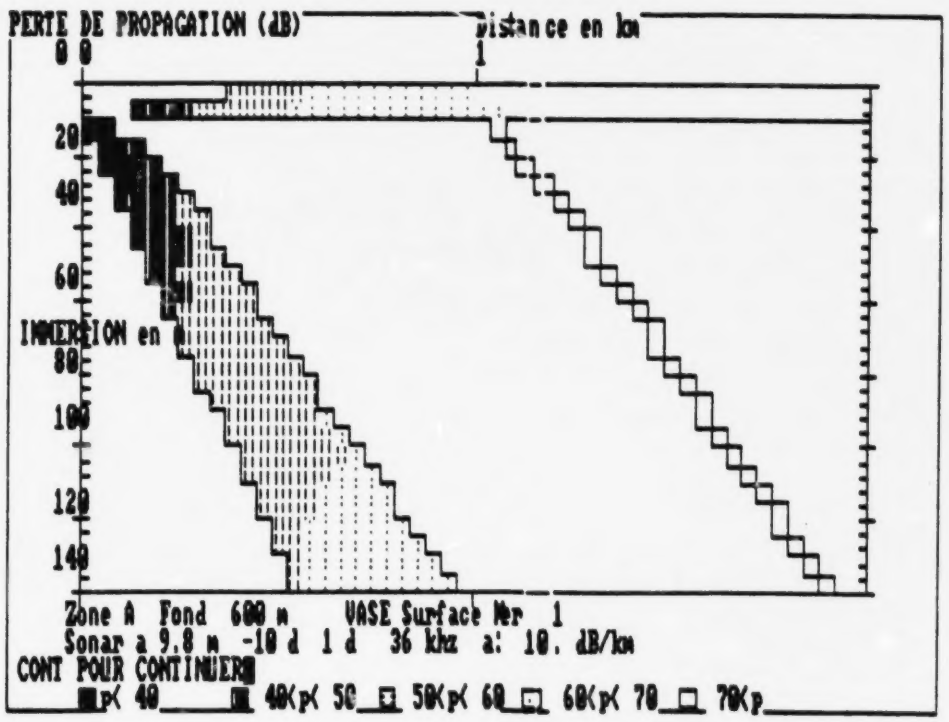
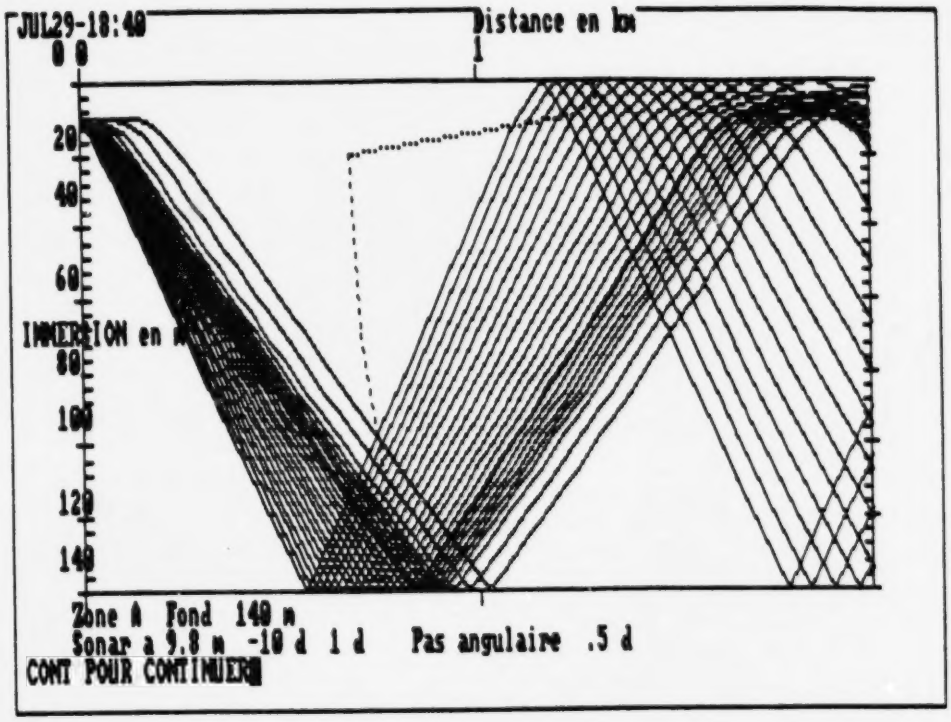


Figure A64 Estimated Propagation on July 28, 21:40 GMT



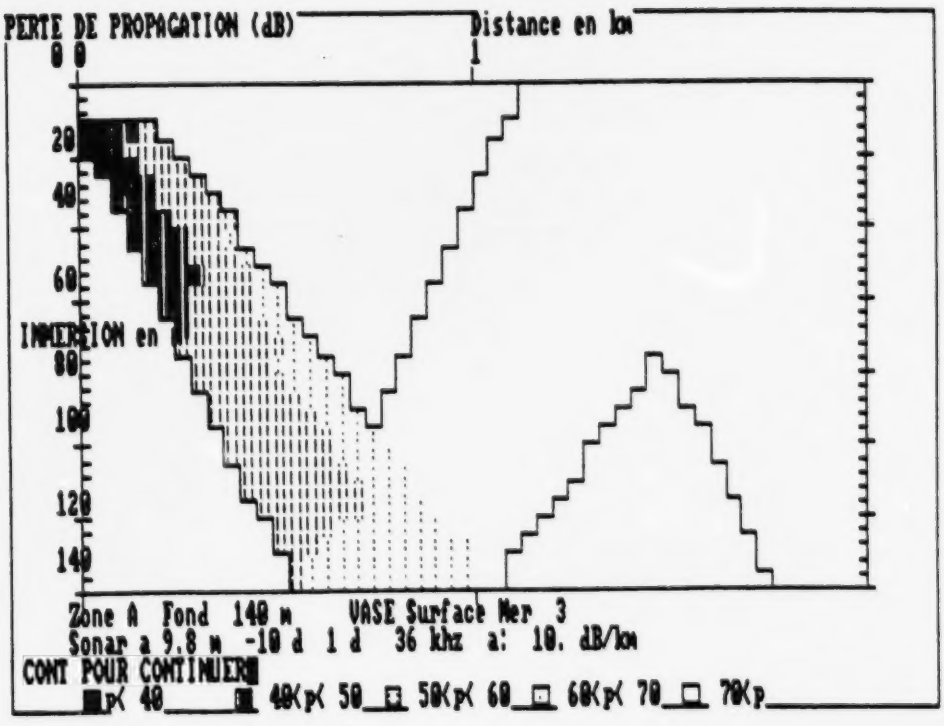
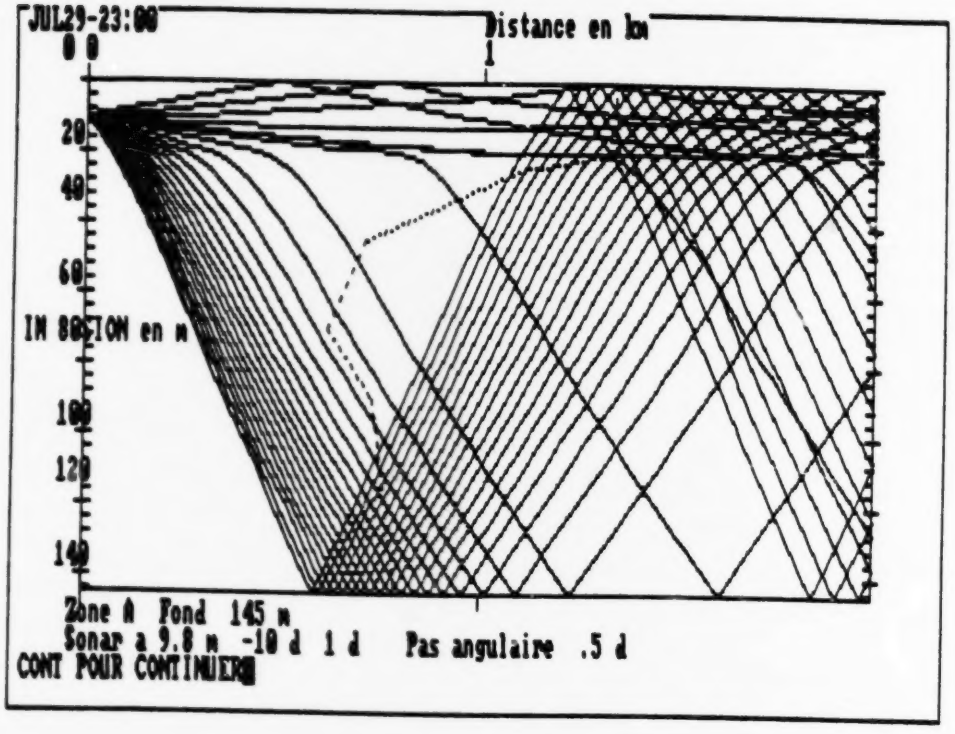


Figure A65 Estimated Propagation on July 29, 18:40 GMT



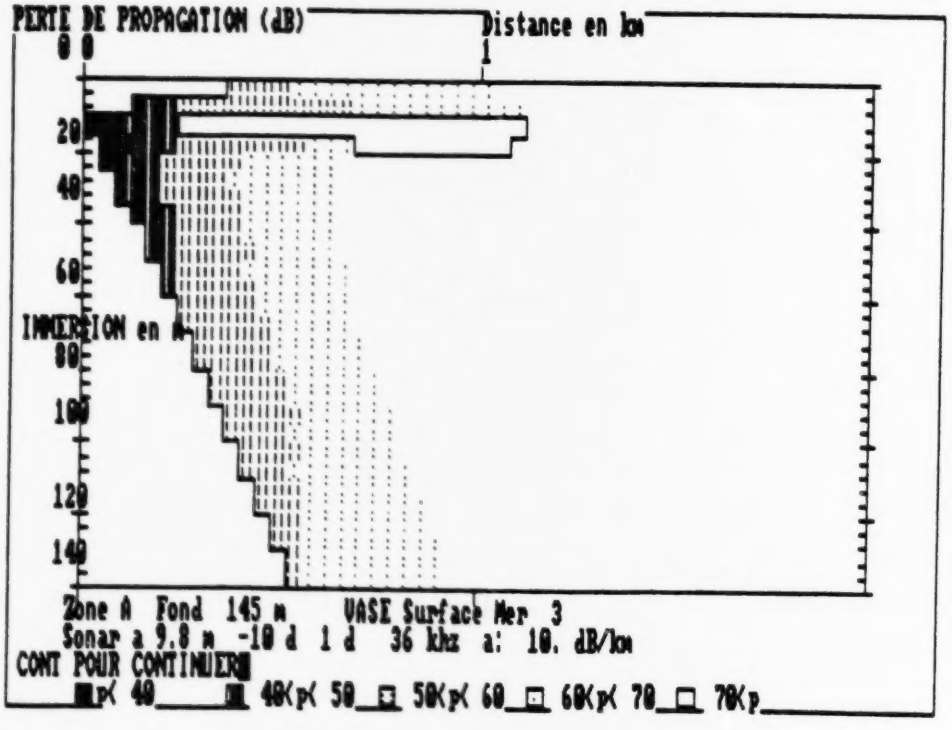
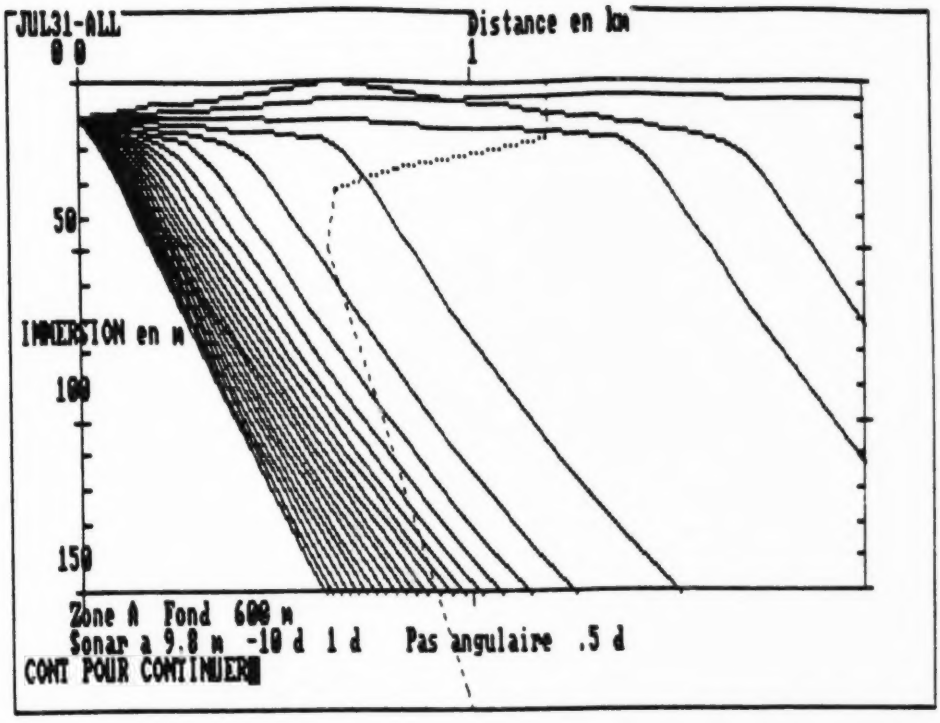


Figure A66 Estimated Propagation on July 29, 23:00 GMT



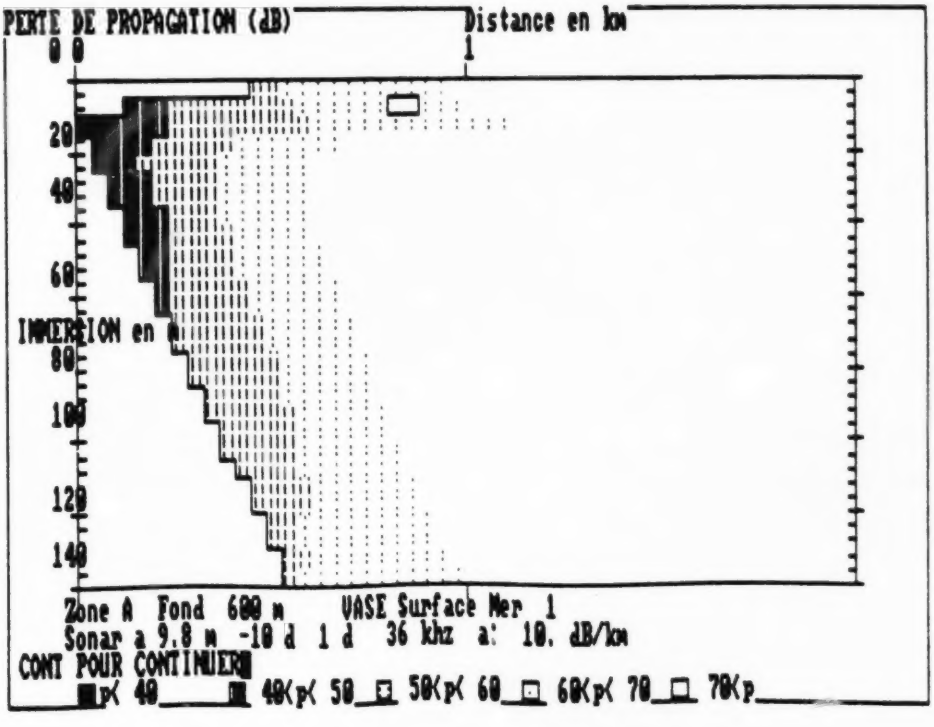


Figure A67 Estimated Propagation on July 31